LAND USE/LAND COVER MAPPING : A REMOTE SENSING APPROACH

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KAUSHLENDRA K OJHA

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C E R T I F I C A T E

This is to certify that the present work entitled, " LAND USE / LAND COVER MAPPING - A REMOTE SENSING APPROACH " has been carried out by Mr. KAUSHLENDRA KUMAR OJHA under my supervision and is not produced anywhere for the award of a degree.

July, 1988.

(DR. K. K. RAMPAL)
Professor
Department of Civil Engineering
Indian Institute of Technology
Kanpur - 208016

CONTENTS

		Page No.
CHAPTER 1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Data Acquisition for study area	3
	1.3 Organization of work	4
CHAPTER 2	PRINCIPLES AND METHODS INVOLVED	7
	2.1 Remote Sensing	7
	2.11 Landsat MSS and TMS	11
	2.1.2 Sensor systems on board the Landsats	15
	2.2 Image Processing	17
	2.2.1 Brightness Maps	18
	2.2.2 Image Enhancement	19
	A)Image Magnification	19
	B)Contrast Enhancement	21
	C)Slicing and gray-scale reversal	22
	D)Linear Strech	23
CHAPTER 3	INFORMATION EXTRACTION	27
	3.1 Introduction	27
	3.2 Initial Statistics Extraction	27
	3.3 Supervised classification	29
	3.3.1 Training sight selection	30
	3.3.2 Feature selection	32
	3.3.3 classification Algorithm	35
	3.3.4 Site-specific classification Map accuracy assessment	38

Page No.

CHAPTER 4	CLASSIFICATION SCHEMES	42
CHAPTER 5	DEVELOPMENT OF PROGRAM	53
	5.1 Software for Statistical Analysis	53
	5.2 Software for classification algorithms	55
CHAPTER 6	RESULTS AND DISCUSSION	60
	6.1 Statistical Analysis	61
	6.2 Land Use Maps	64
	6.3 Field Survey	65
	6.4 Discussion Over Land Use Map	65
	6.5 Accuracy assesment	71
	6.6 Conclusion	71
	6.7 Further recommendations	72
BIBLIOGRAPHY		101
PROGRAM LISTING		103

ABSTRACT

Land use and Land cover information is very important for the resource planners. Hence this study tendsto have immense socio-economic importance. The use of panchromatic medium - scale aerial photographs and latter the use of small scale photographs added with sattelite pictures have helped a lot in this sphere. The use of LANDSAT MSS data though having a coarse resolution are of use for this planning. Using 80 m resolution data the accuracy of 75% has been obtained. Certainly this situation has scope of development by using the sensor data that have good resolution as compared to the LANDSAT MSS. The use of Bayes classifier with a-priori information about the Land use pattern can certainly improve the accuracy of prepared Land use maps. The repetative nature of data available from sattelites helps in assessing the temporal, spatial changes of Land resources and hence justify their use.

CHAPTER 1

INTRODUCTION

1.1 Introduction :

Land use and land cover data are essential to planners who have to make decisions concerning land resource management. Hence they tend to have immense economic importance. The term land cover relates to the type of features present on the surface of the earth. Urban buildings, lakes, rivers, vegitation and roads are all examples of land cover types. The land use is man's activities on and in relation to a specific piece of land. Land use has been studied from many diverse viewpoints so that no one single definition is really appropriate in all different contexts. It is possible, for example, to look at land use from land capability point of view by evaluating the land in relation to various natural characteristics namely climate, geology, soil, hydrology, topography and biology.

Since land cover includes physical structures built by human being, biotic phenomena such as natural vegitation, agricultural crops and animal life and any other type of development, based on the observation of

land cover as proxy, one hopes to infer human activities and land use. However, there are human activities that may not be directly related to the type of land cover, such as recreational activities. Other problems include multiple use which may occur simultaneously or alternately; vertical arrangement of uses and the minimum area size of mapping. Therefore, land use and land cover mapping require some arbitrary decisions to be made and the resultant maps inevitably contain some degree of generalized information according to their scales and purposes of applications.

The use of panchromatic, medium - scale aerial photographs to map land use has been an accepted practise since 1940s. More recently, small scale aerial photographs and satellite images have been utilized for land use/land cover mapping of large areas. The development of improved sensors to provide high spatial resolution (LANDSAT TM, SPOT and future IRS) has made it possible to derive more and more information on land cover/land use from remotely sensed data. The availability of satellite image data in different forms has attracted the flood of applications in the land use and land cover mapping field. The advantage of satellite data are numerous. For the purpose of land use mapping, the wide and repetitive coverage afforded

by the satellite platforms are specially important with regard to the cost effectiveness of collecting and the ease of updating the land use data. Initially, the applications tended to concentrate on a manual approach of extracting the land use data and producing maps. With the more general availability of software packages for mainframe computer and specialized computer based image analysis systems, digital analysis of the satellite data, particularly those from landsat, has become standard in recent years, although the role played by the manual approach continues to be important in developing countries.

1.2 DATA ACQUISITION FOR STUDY AREA

The study area was chosen as a portion of land enclosed between 25°15'N (lat), 25°35'N (lat), 83°00'E (long.) and83°15'N (long.). It covered bulk of Varanasi district and parts of Jaunpur and Ghazipur districts.

The relevant data for land use mapping of the study area were derived from three sources, namely a) the CCT containing the brightness digital number (DN) values, b) the topographical sheets for concerned area and last though not the least c) the 'ground truth'.

The computer compatible tape for the area was acquired from National Remote Sensing Agency (NRSA), Hyderabad. It contained MSS data from the LANDSAT satellite, received under cooperation agreements with United States at the Shadnagar earth station of NRSA, Hyderabad. This CCT covering the scene identified by path number - row number 142 - 042 was created in four bands inter leaved BIL format on June 8th, 1986.

The toposheets required for the present work were made available by the Survey of India.

The field work for collection of ground truths was conducted in the mentioned study area. It would not be wrong to presume that the land use pattern have undergone a change since creation of imagery, yet it was most appropriate to rely upon as the change was not considerable in a span of less than two years at least in built up areas, land under cultivation, highways and railways. The details of field work will be presented at appropriate place.

1.3 ORGANIZATION OF WORK

The course of present work is well described in following steps - Step 1. The number of land use classes was decided after a careful study of the toposheets and other information available for the area. Once the possible

classes that could be identified was decided taking into consideration the resolution of MSS data, 40 training points were selected in each area representing different land use classes. The reflectance DN values for these training points in all the four bands constituted the training data set to be used for classification purpose in following steps.

Step 2 - Statistical analysis of training data set was performed and divergences were calculated to show the separatibility of different classes (land use). This divergence test gives a very good picture of the land use classes that could be classified uniquely. It also gives the information about the most economical band combination for classification purpose.

Step 3 - Based on the statistical data obtained in step 2, different pixels represented by DN values are classified as one of the many land use classes decided already in step 1. A line printer land - use map is prepared once all the pixels are classified. Area falling under different class is calculated at the same time to make obvious the land use pattern adopted in the study area.

<u>Step 4</u> - The field work gave an opportunity to asses the accuracy of prepared land use map. The facts on the map ie the class under which a particular area was envisaged to be, was cross checked with the ground truth during the field work.

CHAPTER 2

PRINCIPLES AND METHODS INVOLVED

2.1 Remote Sensing

Remote sensing is the science of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. The prime objective of remote sensing is to extract environmental and natural resources data related to our earth. Information about the object concerned is conveyed to the observer through electromagnetic energy which is the information carrier and provides communication link. Thus remote sensing data is basically wavelength - intensity information which needs to be decoded before message can be fully understood. This decoding process is analogus to the interpretation of remotely sensed imagery which impinges heavily on ones knowledge of properties of EM radiation.

The principles involved in EM radiations are too well known to be elaborated here. One point that needs to be emphasized here is that the interaction of these radiations with atmosphere and earth surface features should be properly understood before hand in order to grasp the essense of remote sensing.

Figure (2.1) schematically illustrates the generalized processes and elements involved in electromagnetic remote sensing of earth resources.

Figure (2.2) gives overview of how remotely sensed data are turned into useful information.

Resolution is a very important parameter in remote sensing. Resolution or resolving power is a measure of the ability of an optical system to distinguish between signals that are spatially near or spectrally similar (Swain and Davis, 1978). The ability to measure a biophysical variable using remote sensing requires careful consideration of four types of resolutions -

1. Spectral,
2. Spatial,
3. temporal and
4. radiometric resolution.

Spectral resolution refers to the dimension and number of specific wavelength intervals in the electro magnetic spectrum to which a sensor is sensitive. Spatial resolution is a measure of the smallest angular or linear separation between two objects that can be resolved by sensor. Temporal resolution of a sensor system refers to how often a given sensor obtains ima-

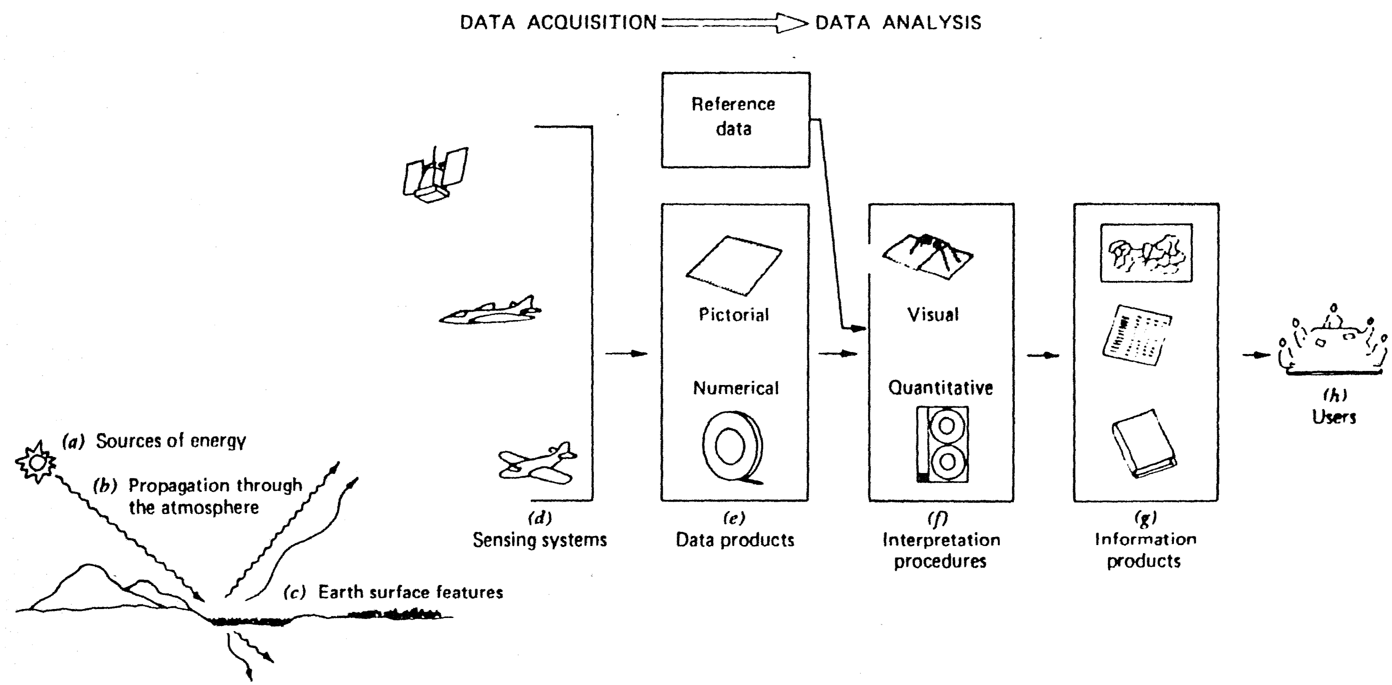

Figure 2. 1 Electromagnetic remote sensing of earth resources.

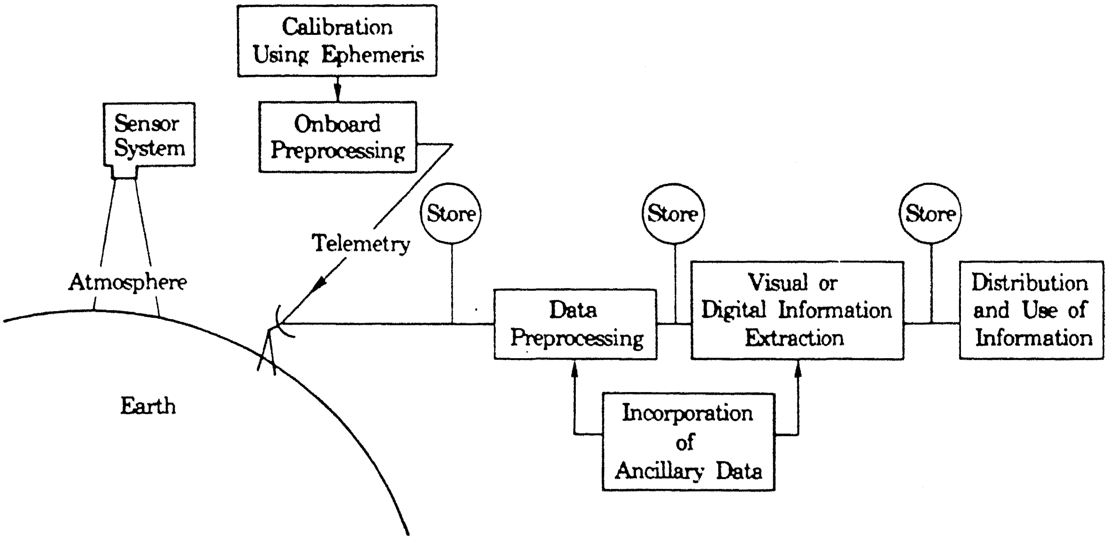

Figure 2–2 Overview of how remotely sensed data are turned into useful information. Once the remotely sensed data are collected, both on-board and ground preprocessing is performed to remove geometric and radiometric distortions. This may involve the use of ephemeris and/or ancillary data. The data are then ready for visual or digital analysis to extract meaningful information. This thematic information is then distributed and hopefully used. (After Landgrebe, 1983.)

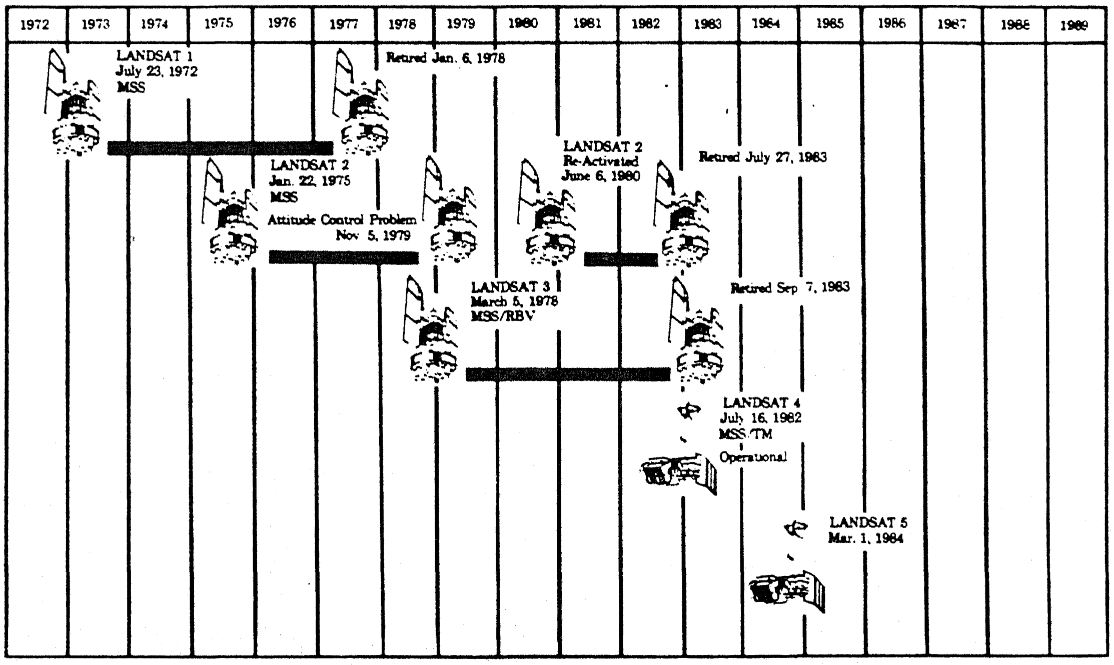

Figure 2–3 Chronological launch and retirement history of the Landsat series of satellites (1, 2, 3, 4, and 5) from 1972 to 1984.

gery of a particular area. Radiometric resolution defines the sensitivity of a detector to differences in signal strength as it records the radiant flux reflected or emitted from the terrain. Radiant flux recorded by thematic mapper sensors on LANDSATs 4 and 5 recorded data in 8 bits (value from 0 to 255) in six of seven bands. Thus the latter system has improved radiometric resolution.

Table (2.1) gives some remote sensor systems functioning from January 1, 1980 to December 31, 1984 and their capability for earth resource mapping.

2.1.1 LANDSAT MULTISPECTRAL SCANNER AND THEMATIC MAPPER SENSOR.

In 1967, the National Aeronautics and Space Administration (NASA) encouraged by US Department of Interior, initiated the Earth Resources Technology Satellite (ERTS) programme. This programme resulted in the deployment of five satellites carrying a variety of remote sensing systems designed primarily to acquire earth resource information. The chronological launch and subsequent retirement history of some of the satellites are shown in Fig. (2.3). The ERTS - 1 satellite launched on July 23, 1972, was the first experimental system designed to test the feasibility of collecting earth resources data by unmanned satellites.

Sensor	System resolutions Spectral	Spatial (ground)	Temporal	Radio metric	Veg.	Soil Rock	Water	Urban
1 Landsat 3								
RBV - return beam vidicon								
Band	0.505-0.75 m	30 x 30m	18 days	6	A	G	L-N	U-W
MSS - multispectral scanner								
Band 4	0.5-0.6	79 x 79	18 days	6	A	G	L,N	U,V
Band 5	0.6-0.7	79 x 79	18 days	6	A,C	G	L	U,V
Band 6	0.7-0.8	79 x 79	18 days	6	C	G	L-N	U,V
Band 7	0.8-1.1	79 x 79	18 days	6	C	G	L-N	U,V
Band 8	10.4-12.6	240 x 240	18 days	6	D	H	O	Y
2 Landsat 4,5								
MSS	as above	as above	16 days	8	As above, except no band 8.			
TM-thematic mapper								
Band 1	0.45-0.52 m	30 x 20m	16 days	8	A,B	G	L-N	U-W
Band 2	0.52-0.60	30 x 30	16 days	8	A	G	L,N	U-W
Band 3	0.63-0.69	30 x 30	16 days	8	A,C	G	L	U-W
Band 4	0-76-0.90	30 x 30	16 days	8	C	G	L-N	U-W
Band 5	1.55-1.75	30 x 30	16 days	8	E	G	L	-
Band 6	10.40-12.5	120 x 120	16 days	8	D	H	O	U
Band 7	2.08-2.35	30 x 30	16 days	8	E	I	L	U

Sensor	System resolutions				Veg.	Soil rock	Water	Urban
	Spectral	Spatial (ground)	Temporal	Radio metric				
3. Aerial Photography (color infrared)								
1:10000	0.5–0.9	0.3 m	Variable	Analog	A–C	G,K	L–N	U–X,Z
1:60000	0.5–0.9	3.0 m	Variable	Analog	A–C	G,K	L–N	U–W,Z
1:130000	0.5–0.9	9.0 m	Variable	Analog	A–C	G,K	L–N	U–W,Z

*Earth resource mapping codes :

Vegetation

A. Chlorophyll concentrations

B. Carotenoid concentrations

C. Biomass

D. Surface temperature

E. Moisture content

Soils and rocks

G. Rock typing and lineament mapping

H. Surface temperature (may include thermal inertia mapping)

I. Hydrothermal alteration

K. Surface roughness

Water

L. Areal extent

M. Land/water boundary delineation

N. Water penetration(may include turbidity

Urban structure

U. Anderson level I

V. Anderson level II

W. Anderson level III

X. Anderson level IV

Y. Surface temperature

Z. Surface roughness.

Table 2.2 : Comparison of Landsat MSS versus Aircraft Areal Coverage.

Platform	Scale	Number of images or photos	
Landsat MSS 1,2, and 3	-	1	
185 x 178km =32,930 km^2			
115 x 111mi =12,765 mi^2			
Low-altitude aircraft	1:15,000	5000	8646
Low-altitude aircraft	1:30,000	1500	2161
High-altitude aircraft	1:60,000	300	540
Commercial jet aircraft	1:90,000	150	240
Government civilian aircraft	1:120,000	85	135
Government military aircraft	1:250,000	30	31

Prior to launch of ERTS - 3 on January 22, 1975, NASA renamed ERTS program landsat, distinguishing it from the seasat oceanographic satellite launched June 26, 1978. At this time ERTS - 1 was retroactively named Landsat - 1 and ERTS - 3 became Landsat - 2 at launch. Landsat 3 was launched March 5, 1978, Landsat 4 on July 16, 1982, and Landsat 5 on March 1, 1984. A variety of mechanical failures prompted the retirement of some of the landsat satellites.

2.1.2 SENSOR SYSTEMS ON BOARD THE LANDSATS.

Sensors carried aloft by the landsat satellites included the multispectral scanner (MSS), return beam vidicon camera (RBV) and the thematic mapper (TM). MSS, placed on all the five landsat satellites, has collected more useful earth resource remote sensor data of the world than any other sensor. Although the measurement of landscape brightness is made from a 6241 Sqm (79m x 79m) area, each pixel is reformatted as if the measurement were made from 4424 Sqm (56m x 79m) area (Fig (2.4)).

Landsat MSS products have provided an unprecedented ability to observe large geographic area within

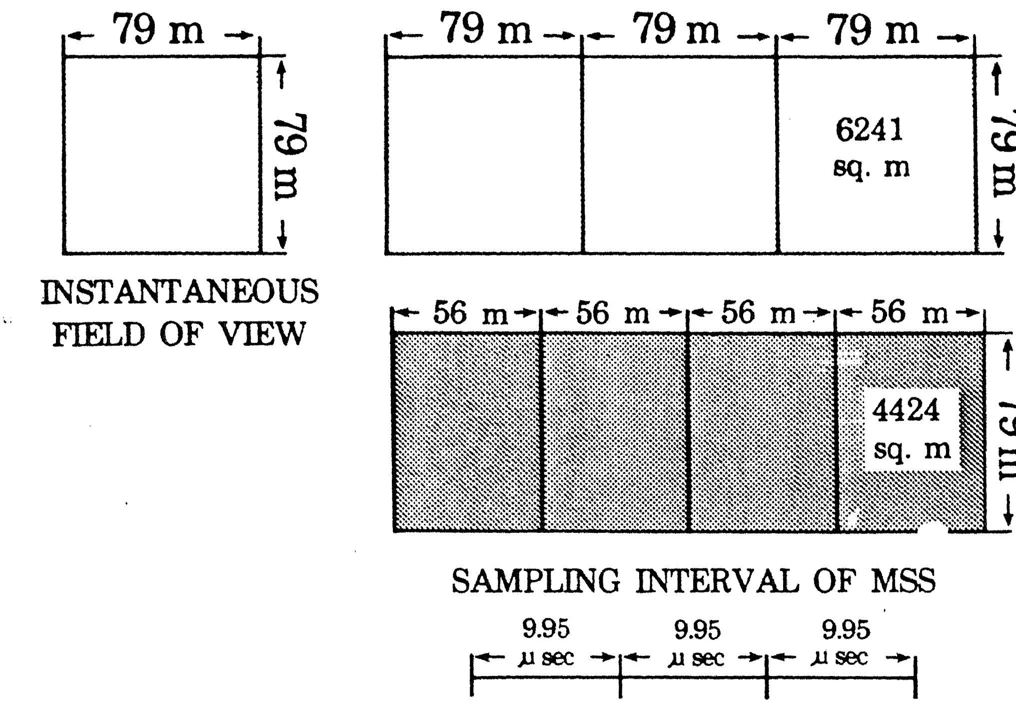

Figure 2-4 Relationship between the original 79 × 79 m IFOV of the Landsat MSS and the rate at which it was resampled (i.e., every 9.95 μs). This resulted in picture elements (pixels) that were 56 × 79 m in dimension on tapes purchased from the EROS Data Center at Sioux Falls, S.D.

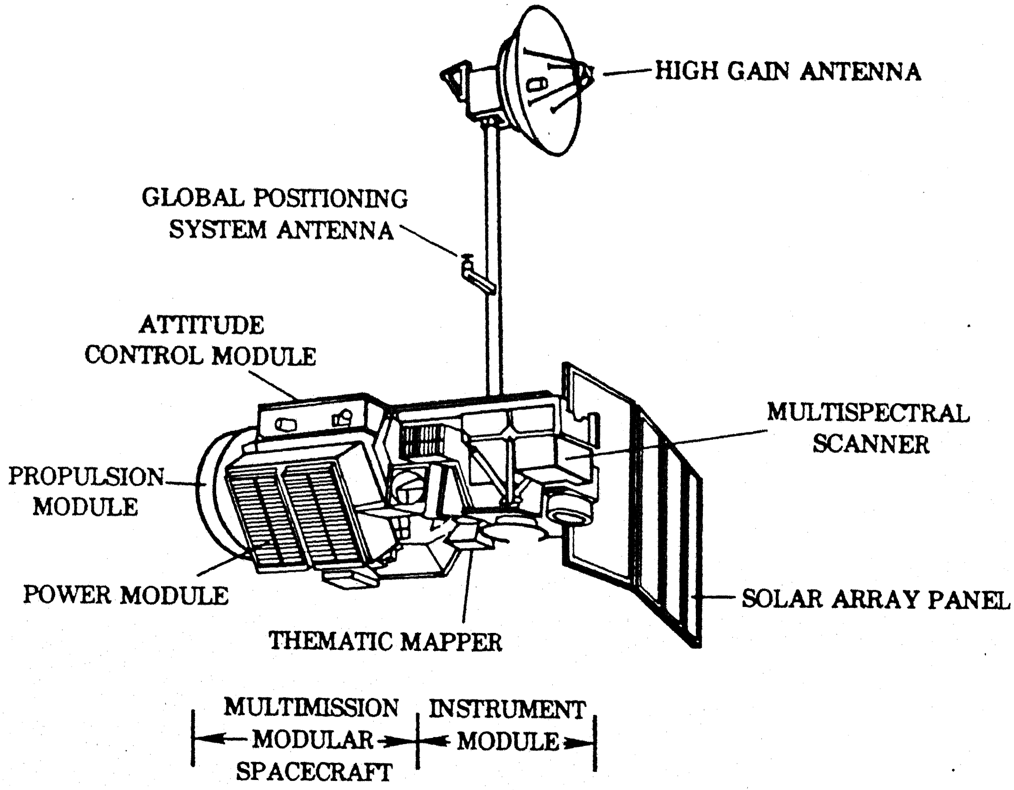

Figure 2-5 Landsat 4 and 5 platform with associated sensor and telecommunication systems.

a single image. This allows regional terrain analysis to be performed using one data source rather than a multitude of aerial photographs (Table (2.2)).

The thematic mapper (TM) sensor system is a scanning optical - mechanical sensor system that records reflected and emitted energy in the visible, reflective - infrared, middle - infrared, and thermal infrared regions of the electromagnetic spectrum. It collects multispectral imagery that has higher spatial, spectral and radiometric resolution than the landsat MSS. The plateform for TM is shown in Fig (2.5).

2.2 IMAGE PROCESSING SYSTEMS.

Once the remotely sensed data are in digital format, it is possible to analyse them using a digital image processing system which can hopefully extract meaningful information from the imagery.

Three approaches are often used to perform digital image processing in educational and research environments (Jensen, 1983). The first is the mainframe approach, where all analysts utilize a mainframe computer ($\geq$ 32 - bits) in batch or interactive mode. They usually work with alphanumeric overprint or line printer output and only occasionally

have the opportunity to view and interactively analy the remote sensor data on a high resolution black-an white or color monitor.

The second approach involves the use of a mini computer (16 - or 32 - bits) an image processor, and high - resolution colour monitor which provide an id image processing environment.

Finally, there exist microcomputer-based (16 - or 32 - bits) image processing systems. Numerous relatively inexpensive microcomputer - based image processing systems may now be acquired for use as multiple workstations in a digital image processing laboratory environment.

2.2.1 BRIGHTNESS MAP.

Answer to the question - How do interpreters convert the brightness values stored on a CCT into an image that begins to approximate the continuous tone photographs they are used to interpreting ? is the creation of Brightness map, also commonly referr to as gray - scale map.

The brightness map is a computer graphic displ of the brightness values found in digital remote sen

data   Ideally, there is a one - to - one relationship between input brightness values and the resultant intensities of output brightness values on display. All brightness values from 0 to 255 would be displayed as a continuum of grays from black to white.

For preparation of remote sensing brightness map two fundamentally different output devices : line printer hard copy and video displays have been used for present work. Fig (2.6) shows a portion of line printer hard - copy.

2.2.2 IMAGE ENHANCEMENT.

Image enhancement algorithms are applied to remotely sensed data to improve the appearance of an image for human visual analysis, or occasionally for subsequent machine analysis. Different image enhancement techniques that were used are given below :

A) Image Magnification.

Digital image magnification (often referred to as zooming) is usually performed to improve the scale of a display for visual interpretation purposes, or occasionally, to match the scale of another image. Column replication represents the simplest form of

Fig 2.6 : A portion of line printer hard copy.

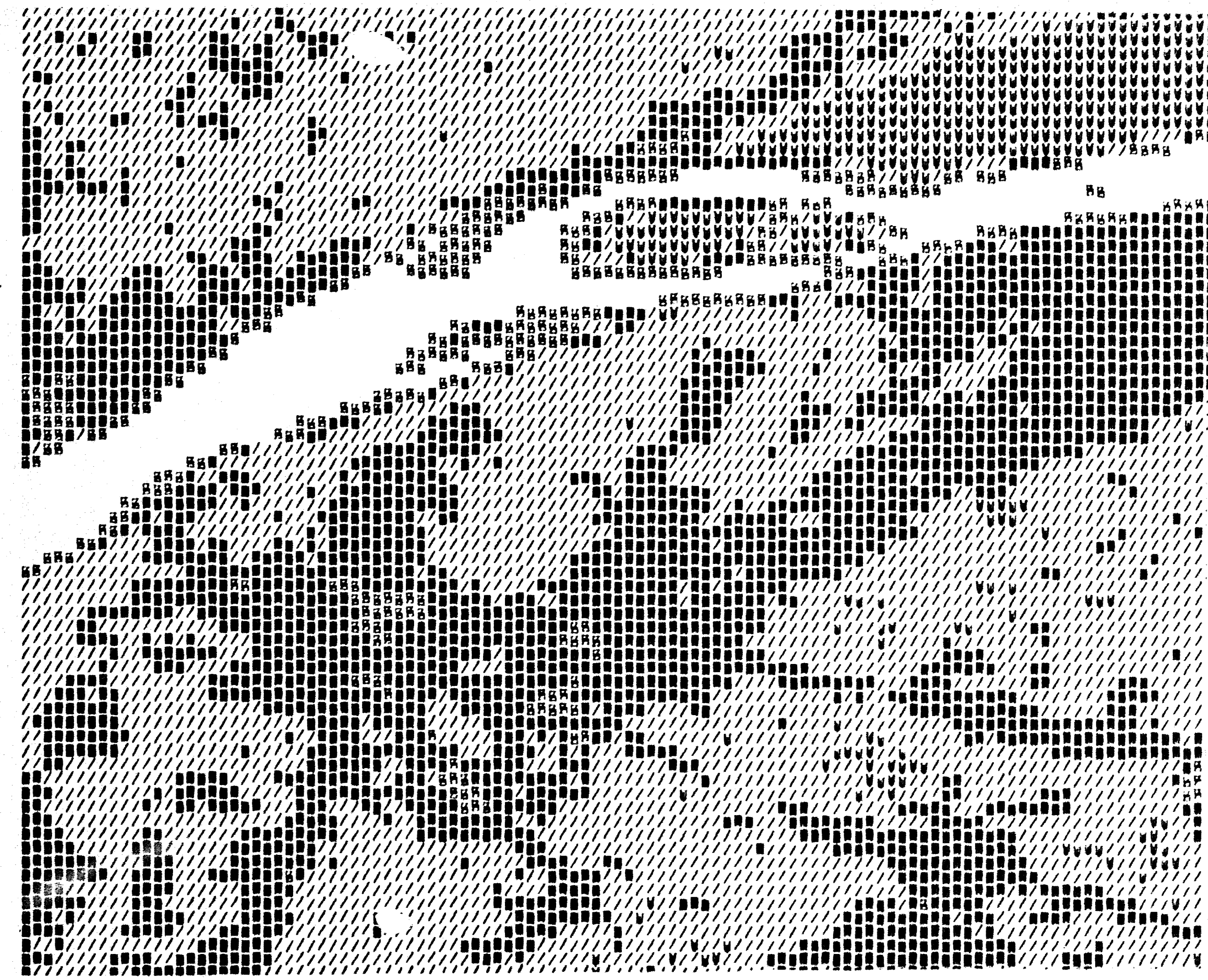

Fig 2.6 : A portion of line printer hard copy.

digital image magnification. To magnify a digital image by a factor m^2, each pixel in original image is usually replaced by an m x m block of pixels, all with the same brightness value as original input pixel. An example of the logic of a four - times magnification is shown in Fig. (2.7).

Original image

0	1	3	2
2	4	2	1
7	8	5	6
4	9	8	7

magnified image

0	0	1	1	3	3	2	2
0	0	1	1	3	3	2	2
2	2	4	4	2	2	1	1
2	2	4	4	2	2	1	1
7	7	8	8	5	5	6	6
7	7	8	8	5	5	6	6
4	4	9	9	8	8	7	7
4	4	9	9	8	8	7	7

Fig.2.7

B) Contrast Enhancement.

Remote sensors record reflected and emitted radiant flux from earth surface materials. Ideally, one material would reflect a tremendous amount of energy in certain wavelengths, while another material would reflect much less energy in the same wavelengths. This would result

in contrast between the two types of materials when recorded by a remote sensing systems. Unfortunately, different materials often reflect similar amounts of radiant flux throughout the visible and near - infrared portions of electromagnetic spectrum, resulting in a relatively low contrast image. In addition, besides this obvious low - contrast characteristic of biophysical materials, there are cultural factors at work. For example, people in developing countries often use natural building materials (eg. wood, soil, etc.) in construction of urban areas. This results in much lower contrast remotely sensed imagery for such areas than for urban areas in developed countries, where concrete, asphalt and fertilized green vegêtation may be more prevelant. Thus digital image contrast enhancement is severly required. Some methods of accomplishing this are detailed below :

a) Slicing and Gray - Scale reversal.

Gray scale adjustment rules can also be specified algebraically. One gray scale adjustment, in such common use that it has been named slicing, can be specified as follows :

$$
\begin{aligned}
G_{adjusted} &= 0 \,; \quad G = 0, 1, 2, \ldots, K \\
&= G \,; \quad G = K+1, K+2, \ldots, M \\
&= 0 \,; \quad G = M+1, M+2, \ldots.
\end{aligned}
$$

The user sets the thresholds K and M. G is the input gray level and $G_{adjusted}$ is output gray level.

Gray - level reversal can also be expressed in a program algebraically as follows :

$$G_{adjusted} = 255 - G$$

where it has been assumed that both the input and output gray levels range from 0 to 255 (8 bit coding).

Linear Stretch

Another special form of gray - scale adjustment, called stretching, is expressed in a program algebraically, as follows :

$$\begin{aligned} G_{adjusted} &= 0 \; ; \quad G = 0, 1, 2, \ldots, K \\ &= (A * G) + B \; ; \; G = K+1, K+2, \ldots, M \\ &= 0 \; ; \quad G = M+1, \ldots, 255 \end{aligned}$$

The parameters A and B are set

$$A = \frac{255}{M-K}$$

$$B = -K * A$$

Again, this assumes an output gray level range of 0 to 255 (8 - bit coding). This linear stretching allows a digital

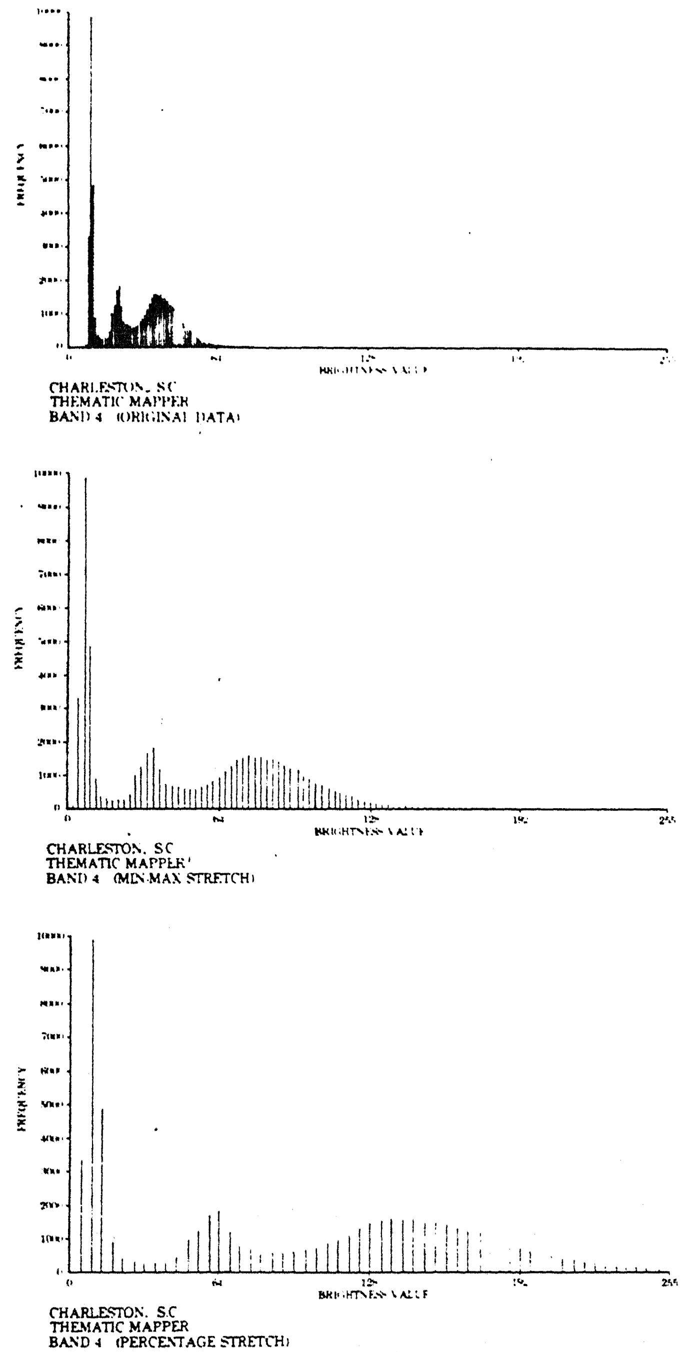

Figure 2.8(a) The histogram of the original band 4 Charleston, S.C., thematic mapper data; (b) the histogram after a minimum-maximum contrast stretch has been applied to the data; (c) the histogram after a 5% linear contrast stretch.

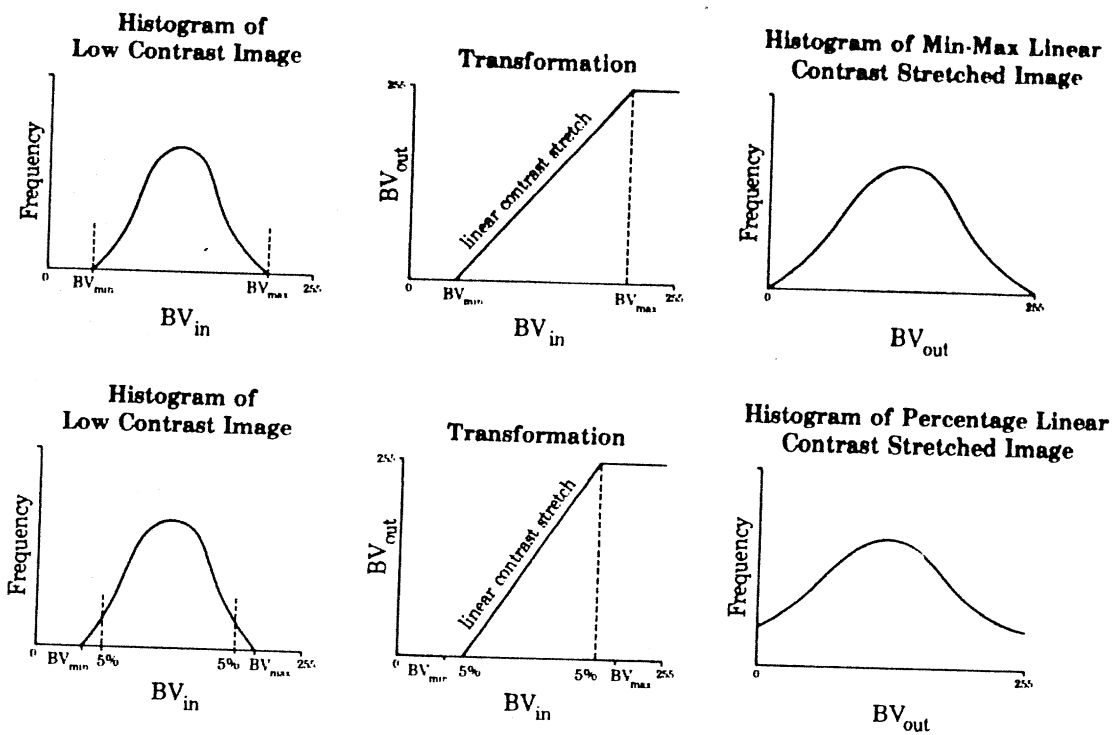

Figure 2.9 Result of applying a minimum-maximum (a) or percentage linear contrast stretch (b) to normally distributed remotely sensed data. The histograms before and after the transformation are shown. Note that bringing the minimum and maximum values in by 5% greatly increases the slope of the linear contrast stretch transformation.

image of restricted gray level range to use the full dynamic range of display device.

Image analysts often specify K and M that lie a certain percentage of pixels 'into' the tails of the histogram. This is called a percentage linear contrast stretch, unlike the earlier one which is called minmax contrast stretch.

The application of these linear stretches to the charleston band 4 TM data resulted into histograms that are shown in Fig (2.8). The logic of such a linear stretch is shown diagrammatically in Fig (2.9).

CHAPTER 3

INFORMATION EXTRACTION

3.1 Introduction :

It is possible to analyze remotely sensed data of the earth and extract useful thematic information. It is to be noted that data are transformed into information. One of the most often used methods of information extraction is multispectral classification. This procedure assumes that imagery of a specific geographic area is collected in multiple regions of electromagnetic spectrum and that the images are in good registration (Fig (3.1)). Most of the information extraction techniques rely on analysis of the spectral reflectance properties of such imagery and employ special algorithms designed to perform various types of "spectral analysis". The process of multispectral classification may be performed using either of two methods : supervised or unsupervised; former being used for present work. But before we start with description of this method, initial statistics extraction of training data set must be dealt with.

3.2 Initial Statistics Extraction :

The mean, standard deviation and variance are

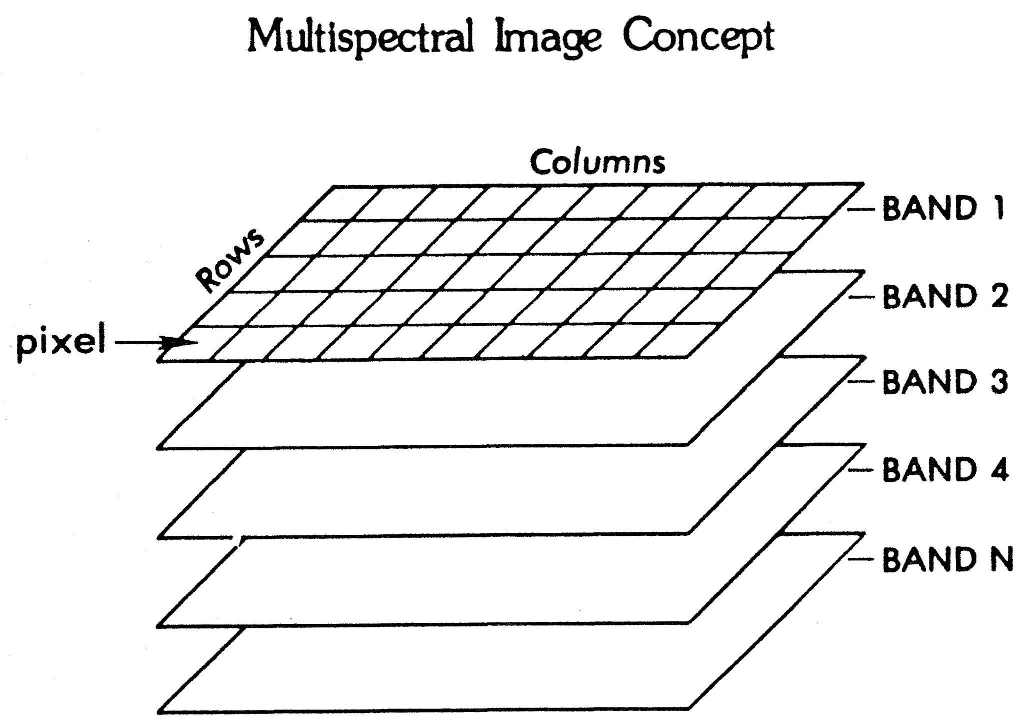

Figure 3–1 To perform multispectral classification the *n*-bands of remotely sensed data must be in perfect registration.

useful measures of central tendency. However, even more useful from a remote sensing standpoint are measures of covariance and correlation among the several bands. Mathematically,

Standard deviation in reflectance values in band k

$$S_k = \frac{1}{n} \sum_{i=1}^{n} (BV_{ik} - \mu_k)^2 ,$$

covariance between bands k and c of sample data

$$Cov_{kc} = \frac{1}{n} \sum_{i=1}^{n} (BV_{ik} \times BV_{ic}) - \mu_k \times \mu_c , \text{ and}$$

correlation coefficient between the data in bands k and c

$$\gamma_{kc} = [\frac{Cov_{kc}}{S_k \times S_c}]$$

They ean provide insight into data redundancy or quality (ie, are the data of any value for the remote sensing task at hand). High coefficient of correlation tends to show substantial redundant spectral information in the concerned channels.

3.3 Supervised Classification:

The following are important aspects of conducting a rigorous and hopefully useful supervised classification of remote sensor data :

1. An appropriate classification scheme must be adopted.

2. Representative training sites must be selected,

3. Statistics must be extracted from the training site spectral data.

4. The statistics are analyzed to select the appropriate feature (bands) to be used in the classification process, this may involve both computer graphic and/or statistical methods of evaluating the degree of between-class separability.

5. Select appropriate classification algorithm.

6. Classify the imagery into m classes.

7. Statistically evaluate the classification accuracy.

It is instructive to review few of these parameters individually to show their significance.

3.3.1 Training Site selection :

Those sites within the image that are representative of the land cover classes of interest may be selected. These sites should not be atypical but ones that represent the norm for each class. The image coordinates of these

sites are then identified and used to extract statistics from the spectral data for each of these areas. Training data should be of value if the environment from which they were obtained is relatively homogeneous.

Each site is usually composed of many pixels. The general rule is that if training data are being extracted from n bands, the minimum number of pixels in a class should be n+1. This condition will allow the inverse of covariance matrix for each class to be calculated, which is important for few classification algorithm. Ideally, >10 n pixels of training data are collected for each class.

If four bands are used for information extraction, then each pixel in each training site is represented by a measurement vector, X_c such that

$$X_c = \begin{bmatrix} BV_{ij1} \\ BV_{ij2} \\ BV_{ij3} \\ BV_{ij4} \end{bmatrix}$$

where BV_{ijk} is the brightness value for the (i,j)th pixel in band k. The brightness value for each pixel in each band in each training class can then be analysed statistically to yield a mean measurement vector, M_c, for each

class :

$$M_c = \begin{bmatrix} \mu_{c1} \\ \mu_{c2} \\ \mu_{c3} \\ \mu_{c4} \end{bmatrix}$$

where μ_{ck} represents the mean value of the data obtained for class c in band k. The raw measurement vector can also be analysed to yield the cowariance matrix for each class c :

$$V_{ckl} = \begin{bmatrix} Cov_{c11} & Cov_{c12} & Cov_{c13} & Cov_{c14} \\ Cov_{c21} & Cov_{c22} & Cov_{c23} & Cov_{c24} \\ Cov_{c31} & Cov_{c32} & Cov_{c33} & Cov_{c34} \\ Cov_{c41} & Cov_{c42} & Cov_{c43} & Cov_{c44} \end{bmatrix} = V_c$$

where Cov_{ckl} is the covariance of class c between bands k through l. For brevity the rotation for the covariance matrix for class c (ie V_{ckl}) will be shortened to V_c.

3.3.2 Feature Selection :

A judgement must be made to determine those bands that are most effective in discriminating each class from all others. This process is commonly called feature selection. The goal is to delete from the analysis those bands

that provide only redundant spectral information. In this way the dimensionality (ie, the number of bands to be processed) in the data set may be reduced.

Statistical methods of feature selection are used to quantitatively select the subset of bands (or features) that provides the greatest degree of separability between any two classes, c and d. Divergence was one of the first measure of statistical separability used in the machine processing of remote sensor data, and it is still widely used as a method of feature selection. It addresses the basic problem of deciding what is the best q-band subset for use in the supervised classification process. The number of combinations, c, of n bands taken q at a time is

$$c\left(\frac{n}{q}\right) = \frac{n!}{q!\,(n-q)!}$$

The degree of divergence or "separability" between two classes c and d, $Diverg_{cd}$, is computed according to the formula

$$Diverg_{cd} = \frac{1}{2} T_{\gamma}\,\{(V_c-V_d)(V_d^{-1}-V_c^{-1})\}$$
$$+\ 0.5\ T_{\gamma}\{(V_c^{-1}+V_d^{-1})\ (M_c-M_d)\ (M_c-M_d)^{T}\}$$

where T_{γ} $\{.\}$ is the trace of a matrix (ie. the sum

of diagonal elements), V_c and V_d are the covariance matrix for two classes, c and d, under investigation, and M_c and M_d are mean vectors for classes c and d.

If there are more than two classes, the average divergence, $Diverg_{avg}$ is computed over all possible pairs of classes c and d, while holding the subset of bands, q constant, as follows :

$$Diverg_{avg} = \frac{1}{c} \sum_{c=1}^{m-1} \sum_{d=c+1}^{m} Diverg_{cd}$$

Kumar and Silva (1977) suggest that it is possible to take the divergence logic one step further and compute transformed divergence, expressed as

$$\overset{T}{Diverg_{cd}} = 2000 \left[1 - \exp\{ \frac{(-Diverg_{cd})}{8} \} \right]$$

This statistic gives an exponentially decreasing weight to increasing distance between the class. It also scales the divergence value to lie between 0 and 2000.

A transformed divergence value of 2000 suggests excellent between - class separation. Above 1900 provides good separation, while below 1700 is poor. For divergence values less than 1500 we get spectrally similar classes.

3.3.3 Classification Algorithm :

Various supervised classification methods may be used to assign an unknown pixel to one of a number of classes. The choice of a particular classifier or decision rule depends on the nature of the input data and the desired output (Friedman, 1980). Parametric classification algorithms assume that the observed measurement vectors X_c obtained for each class in each spectral band during the training phase of supervised classification are Gaussian in nature (ie, they are normally distributed). Nonparametric classification algorithms make no such assumption. For present work maximum likelyhood decision rule which is a special case of Bayes' decision rule, is used.

This decision rule assigns each pixel having pattern measurements or features X to the class G whose units are most probable or likely to have given rise to feature vector X.

It can be proved mathematically that this rule minimize the "Total Error of Classification". If there are 'G' groups or classes then according to Bayes' Rule, assign the measurement X to group i where :

$$P(G_i/X) > P(G_j/X) \quad \text{for all } i \neq j.$$

Now according to "Bayes Theorem of Conditioned Probability"

$$P(G_i/X) = \frac{P(X/G_i)\ P(G_i)}{\text{Sum of all } P(X/G_i)P(G_i)} = \frac{P(X/G_i)\ P(G_i)}{\Sigma_i\ P(X/G_i)\ P(G_i)}$$

where $P(G_i)$ = Probability of class 'i'

Thus the final form of Bayes Rule is

$$P(X/G_i)\ P(G_i) > P(X(G_j)\ P(G_j)$$

for all $j \neq i$

To apply Bayes' Rule we have to know the value of $P(G_i)$ and $P(X/G_i)$ for each group. It can be shown that it is easy to find the value of $P(G_i)$ but not so far $P(X/G_i)$.

Now if we assume that if within each group the variables that make up the measurement vector X have a multivariate Norm distribution, then the form of conditional probability $P(X/G_i)$ is given by the density function :

$$P(X/G_i) = \frac{1}{(2\pi)^{n/2}\ |V_i|^{1/2}} \exp\left(-\frac{1}{2}(X-M_i)\ V_i^{-1}\ (X-M_i)^t\right)$$

where M_i = mean of class of group i

V_i = variance covariance matrix of class 'i'

$P(G_i)$ = A priori probability of class 'i'

$(X-M_i)^t$ = Transpose of $(X-M_i)$.

Therefore estimating $P(X/G_i)$ comes down to estimating two parameters, M_i the group mean vector and V_i the group covariance matrix. If there are n measurements in X (Bands or channels) then there are 'n' group means in the mean vector and $\frac{n(n+1)}{2}$ elements is the cowariance matrix making a total of $\frac{n^2+3n}{2}$ quantities to be estimated for each group but this is considerably fewer than the number of required for a direct application of Bayes rule using estimates of relative frequencies.

Using the normal form of $P(X/G_i)$ in Bayes rule we have :

Assign X to G_i if

$$\left[\ln|V_i| + (X - M_i)\ V_i^{-1}\ (X - M_i)^t - 2\ln P(G_i)\right] >$$

$$\left[\ln|V_j| + (X - M_j)\ V_j^{-1}\ (X - M_j)^t - 2\ln P(G_j)\right]$$

for all $j \neq i$

Although matrix operation are involved in working out the above expressions, the final result is a number for each group which depends on X. This quantity is often referred to as <u>Discriminant Score</u> and the expression d_i

$$d_i(X) = \ln|V_i| + (X - M_i)\ V_i^{-1}(X - M_i)^t$$

is called a "<u>Discriminant Function</u>".

<u>As a final rule</u> for Bayesian method of classification, Assign the measurement X to the group with the <u>smallest</u> value of $d_i(X) - \ln P(G_i)$, we can infer that as $d_i(X)$ gets smaller, the evidence of members of group 'i' increases which is the opposite to the behaviour of $P(G_i/X)$. Even though $d_i(X)$ does not behave like $P(G_i/X)$. It is important to realise that the rule :-

Assign to group 'i' if :

$$d_i(X) - \ln P(G_i) < d_j(X) - \ln P(G_j) \quad \text{for all } j \neq i$$

is the Baye's rule if X is multivariate Normally distributed in each of the classes or group.

This Bayes' decision rule is identical to the maximum likelihood decision rule except that it does not assume that each of the class is equally probable. A priori probabilities have been used succesfully as a way of incorporating the effect of releif and other terrain characteristics in improving classification occuracy.

3.3.4 <u>Site - Specific classification Map accuracy assessment</u> :

This type of error analysis compares the accuracy of the remote sensing - derived classification map pixel by pixel

with the assumed true land map. A number of strategies have been developed.

First, it is possible to conduct a site - specific error evaluation based only on the training pixels used to train the classifier in a supervised classification. This simply means that those pixel locations i,j used to train the classifiers are carefully evaluated on both the remote sensing - derived classification map and the true map. If training samples are distributed randomly throughout the study area, this evaluation may be considered representative of the study area. Unfortunately, the locations of training sites are usually nonrandom - they are biased by the analyst's a priori knowledge of where certain land cover types exist in the scene. Because of this bias, the classification accuracies for pixels found within the training sites are generally higher than for the remainder of the map because these are data locations that were used to "train" the classifor.

Conversely, if other test locations in the study area are identified and correctly labeled prior to the classification and if these are not used in training of the classification algorithm, they can be used to evaluate

the accuracy of classification map. This procedure generally yields a more credible classification accuracy assessment. However, additional "ground truth" is required for these test site areas, coupled with the problem of identifying how many pixels are necessary in each test site class.

The ideal number of points to be tested in the land - use classification map was determined from the formulas for the binomial probability theory. The formula for the number of points selected was :

$$N = \{ \frac{4(p)\ (q)}{E^2} \}$$

where p is the expected percent accuracy, q the difference between 100 and p, E the allowable error, and N the number of points to be sampled (Fitzpatrick - lins, 1980).

Once the criterion for objectively identifying the location of specific pixels to be compared is determined, it is necessary to identify the class assigned to each data are tabulated and reported in a contingency table, where overall classification accuracy and misclassification between categories are identified.

There are two types of errors :

1. A pixel may be assigned to a class to which it does not belong (an error of commission).

2. A pixel is not assigned to its appropriate class (an error of omission).

The off-diagonal enteries provide information on errors of omission and commission. Errors of commission are found in the lower left half of the matrix, while errors of omission are found in the upper right half of the matrix. Errors of omission for each class are computed by summing the number of pixels assigned to incorrect categories along each row and dividing this number by the total number of true pixels in the category. Errors of commission are computed by summing the number of pixels assigned to incorrect categories along each column and dividing this number by the total number of pixels assigned to the column category.

CHAPTER 4

CLASSIFICATION SCHEMES

One crucial factor in determining the success of land use and land cover mapping lies in the choice of an appropriate classification scheme designed for an intended purpose. A good classification scheme should be easy to use with no ambiguity in defining each land use and land cover category. It must also be able to generate the degree of details required. Certain classification schemes have been developed that can radily incorporate land use and/or land cover data obtained by interpreting remotely sensed data, namely US Geological survey land use/land cover classification system, the Michigan classification system, the Cowardine Wetland classification system, etc.

Major points of difference between various classification schemes are their (1) emphasis, and (2) ability to incorporate information obtained using remote sensing. For example, USGS (Anderson et al., 1976), is "resource" oriented in contrast with various "people or activity" oriented systems such as Standard Land Use Coding (SLUC) manual (Urban Renewal Administration, 1965). The USGS rationale is that "although there is an obvious need for an urban - oriented land - use classification system, there is also a need for a resource -

oriented classification system whose primary emphasis would be the remaining 95 percent of United States land area ". The system addresses this need with eight of the nine level I categories treating land area that is not in urban or built-up categories (Table 4.1). The system is designed to be driven primarily by the interpretation of remote sensor data obtained at various scales and resolutions (Table 4.2) and not data collected in situ. It was initially developed to include land use data that was visually interpreted, although it has been widely used for digital multispectral classification as well. Land use/land cover data classified according to this system is compatible with land use coding used in the US Geological Survey's Geographic Information Retrieval and Analysis System (GIRAS) (Mitchell et al., 1977).

The USGS land use and land cover classification system was designed according to the following criteria: (1) the minimum level of interpretation accuracy using remote sensor data should be at least 85 percent; (2) the accuracy of interpretation for the several categories should be about equal; (3) repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another; (4) the

Table 4.1 : U.S. Geological Survey Land Use/Land Cover Classification System for Use with Remote Sensor Data.

Level I		Level II
1	Urban or built-up land	11 Residential 12 Commercial and services 13 Industrial 14 Transportation, communication and services 15 Industrial and commercial complexes 16 Mixed urban or built-up land 17 Other urban or built-up land
2	Agricultural land	21 Cropland and pasture 22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas 23 Confined feeding operations 24 Other agricultural land
3	Rangeland	31 Herbaceous rangeland 32 Shrub and brush rangeland 33 Mixed rangeland
4	Forest land	41 Deciduous forest land 42 Evergreen forest land 43 Mixed forest land
5	Water	51 Streams and canals 52 Lakes 53 Reservoirs 54 Bays and estuaries
6	Wetland	61 Forested wetland 62 Nonforested wetland
7	Barren land	71 Dry salt flats 72 Beaches 73 Sandy areas other than beaches 74 Bare exposed rocks 75 Strip mines, quarries, and gravel pits 76 Transitional areas 77 Mixed barren land
8	Tundra	81 Shrub and brush tundra 82 Herbaceous tundra 83 Bare ground 84 Mixed tundra
9	Perennial snow and ice	91 Perennial snowfields 92 Glaciers

Source : Anderson et al. (1976).

Table 4.2 : The four levels of the U.S. Geological Survey Land Use/Land Cover Classification System and the Type of Remotely Sensed Data Typically Used to Provide the Information.

Classification level	Typical data characteristics
I	Landsat (formerly ERTS) type of data.
II	High-altitude data acquired at 40,00 ft (12,400 m) or above; results in imagery that is less than 1:80,000 scale.
III	Medium-altitude data acquired betwee 10,000 and 40,000 ft (3100 and 12,40 m); results in imagery that is betwe 1:20,000 and 1:80,000 scale.
IV	Low-altitude data acquired below 10,0 ft (3100 m); results in imagery that larger than 1:20,000 scale.

Source: Anderson et al. (1976) and Jensen et al. (1983). (c) American Society of Photogrammetry and Remote Sensing.

classification system should be applicable over extensive areas; (5) the categorization should permit land use to be inferred from the land cover types; (6) the classification system should be suitable for use with remote sensor data obtained at different times of year; (7) categories should be divisible into more detailed subcategories that can be obtained from large scale imagery or ground surveys; (8) aggregation of categories must be possible; (9) comparison with future land use and land cover data should be possible; and (10) multiple uses of land should be recognized when possible.

The system is designed to use four "levels" of information, two of which are detailed in Table 4.1. The USGS classification system also provides for the inclusion of more detailed land use/land cover categories in levels III and IV. These two levels can be utilized to provide information at a resolution appropriate for regional (multicountry), country or local planning, and management activities. It is intended that levels III and IV be designed by the local users of the USGS system, keeping in mind that the categories in each level must aggregate into the categories in the next higher level. Fig. (4.1) shows a sample aggregation of classifications for levels III, II and I.

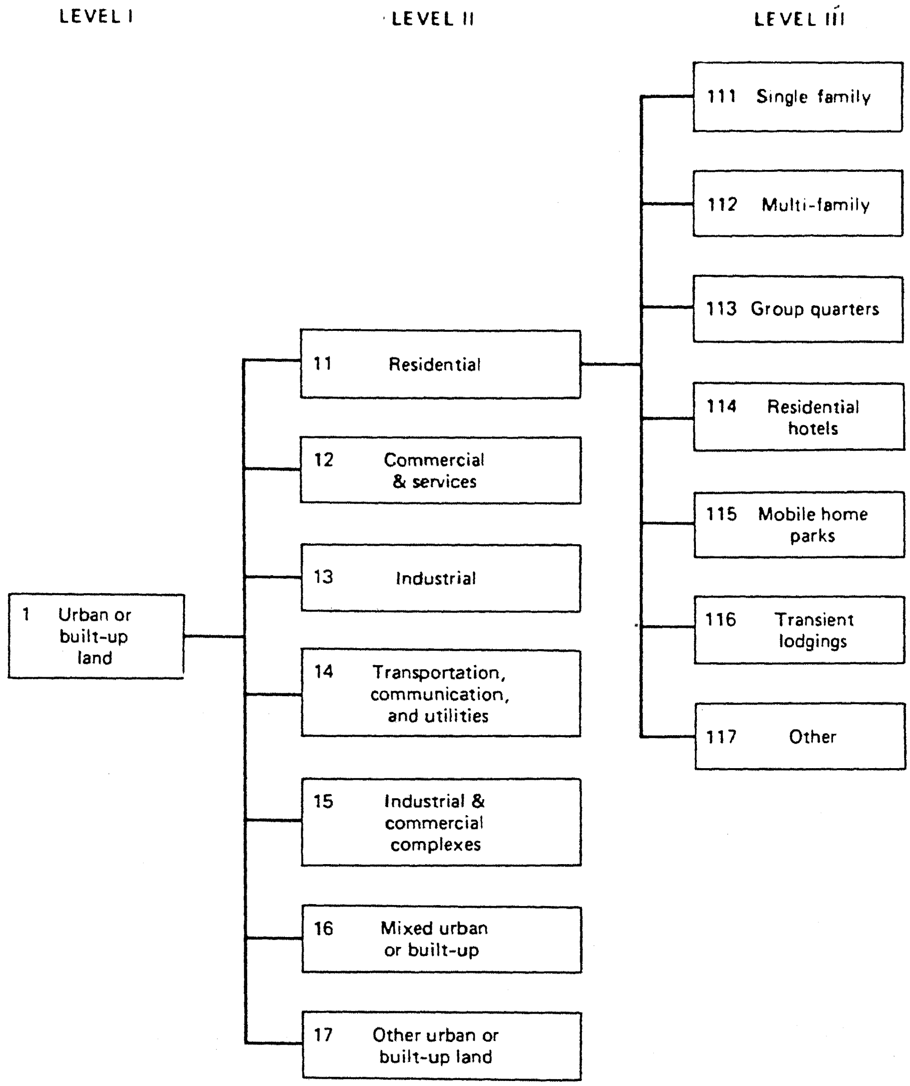

Figure 4.1 An example of aggregation of land use/land cover types.

Cowardin et al. (1979) developed a wetland classification system that incorporates information extracted from remote sensor data and in situ measurements. It describes ecological taxa, arranges them in a system useful to resource managers, and provides uniformity of concepts and terms (Fig (4.2)). Wetlands are classified based on plant characteristics, soil and frequency of flooding.

Finally, it should be noted that there is a relationship between the level of detail in a classification scheme and spatial resolution of remote sensor systems used to provide information. For example, Welch (1982) summarised this relationship for mapping of urban/suburban land use and land cover in United States (Fig 4.3)). A similar relationship exists when mapping vegetation (NASA, 1983). For example, the sensor systems and spatial resolutions useful for discriminating vegetation from a global to an in situ perspective are summarised in Figure (4.4). This suggests that the level of details in desired classification system dictates the spatial resolution of remote sensor data that should be used. Spectral resolution is also an important consideration. However, it is not as

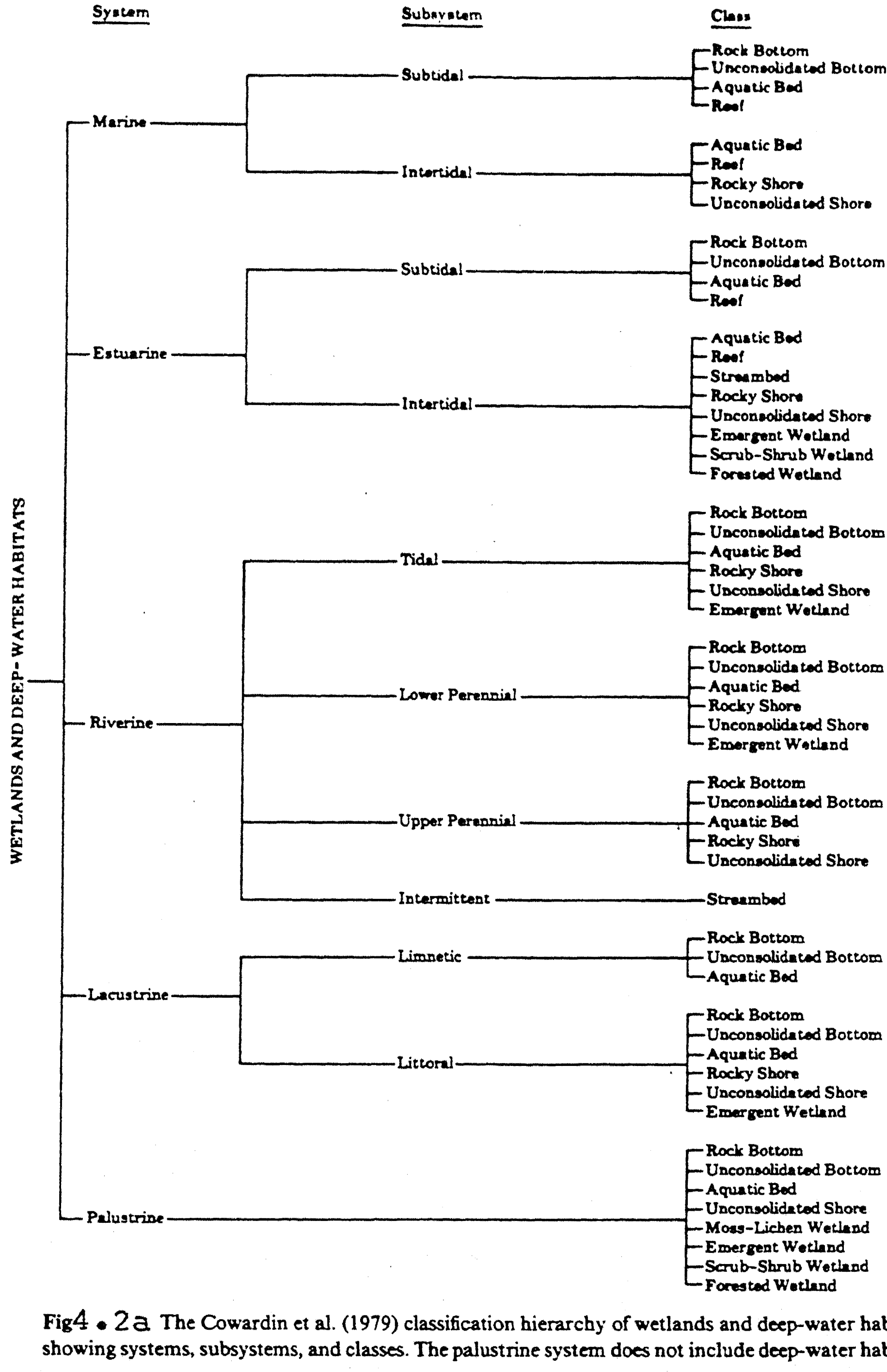

Fig4 • 2a The Cowardin et al. (1979) classification hierarchy of wetlands and deep-water habitats, showing systems, subsystems, and classes. The palustrine system does not include deep-water habitats.

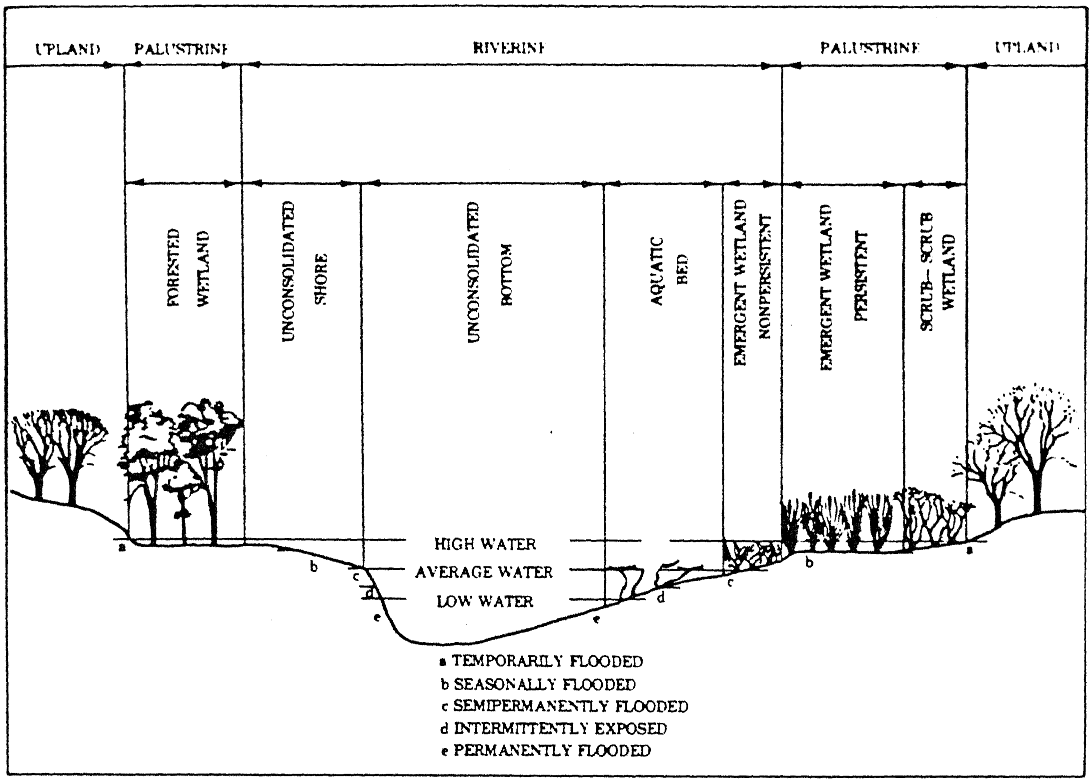

Fig4 • 2b Distinguishing features and examples of habitats in the riverine system. (Cowardin et al., 1979.)

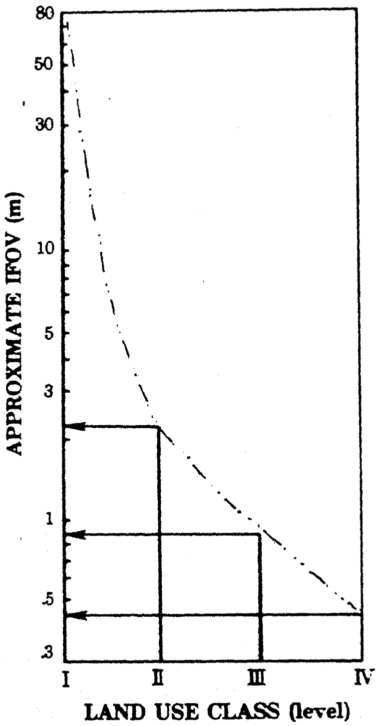

Figure 4 • 4 Spatial resolution (IFOV) requirements as a function of the mapping requirements for levels I to IV land-use classes in the United States (based on Anderson et al., 1976). Levels I, II, III, and IV information are normally derived from satellite, high-, medium-, and low-altitude image data, respectively. Note the dramatic increase in resolution required to map level II classes. (From Welch, 1982; Jensen et al., 1983.) © American Society of Photogrammetry. Used with permission.

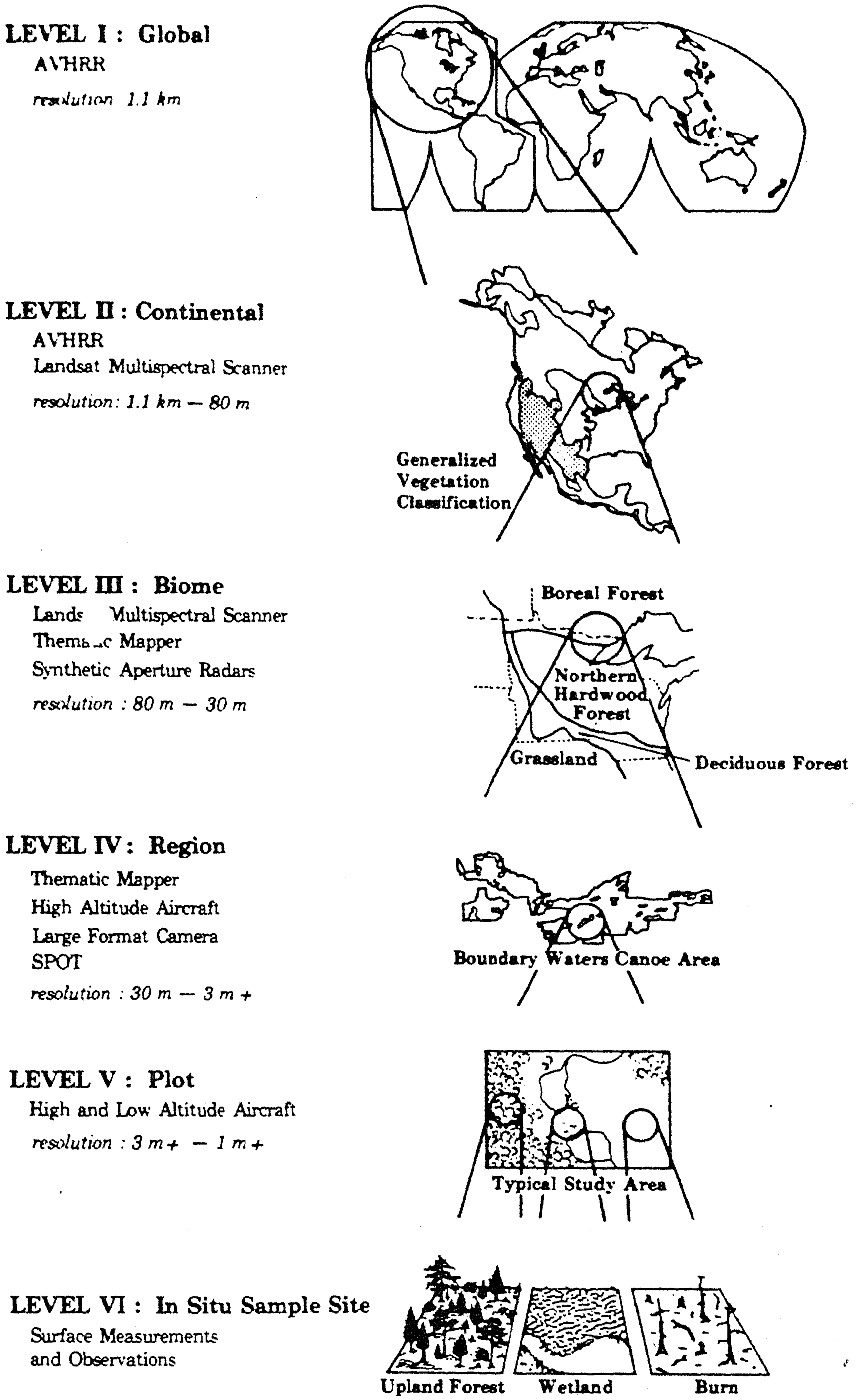

Figure 4.3 Relationship between the level of detail required and the spatial resolution of various remote sensing systems for vegetation inventories. (From NASA, 1983; Botkin et al., 1984.)

critical a parameter as spatial resolution since most of the sensor systems record energy in approximately the same visible and near infrared portions of the electromagnetic spectrum.

CHAPTER 5

DEVELOPMENT OF PROGRAM

Software development was most essential part of present thesis work. It is needless to reiterate that this work was based on digitized data obtained in form of computer compatible tapes (CCT's) and manual approach for data interpretation through analysis of these data, which was enormous would have been an unnerving task and all the benefits of using satellite platøform for data collection would have been eroded. In this context the swiftness and accuracy associated to digital computer in land use/land cover mapping ought to be appreciated.

5.1 Software for statistical analysis.

Statistical analysis of training data was performed by program STATAN. It used different subroutines to get the maximum, minimum, mean, standard deviation, covariance and coefficient of correlation between brightness value digital number associated to different pixels in a particular class and particular spectral band. The functions performed by different subroutines used in this program are listed below.

STAT01 - parametric inputs to this subroutine are number of classes (ICLASS) and number of pixels used for training

the classifier to identify any particular class (IDATA). This subroutine reads the brightness values of training points in array TD. It performs the statistical analysis and returns the minimum, maximum, mean, variance - co-variance, inverse variance - covariance matrix and coeff-icient of correlation matrix. At the same time it returns the determinant of variance - covariance matrix to be used for classification subroutine (STATO3). This subroutine also makes use of two NAG library subroutines (FO1AAF and FO3AAF).

STATO2 - this subroutine performs two multiplication operations given below

$$PRO = \{RD\}^T \; A \; \{RD\}$$

vector {RD} and matrix A are input to this subroutine to produce PRO as output.

STATO3 - this subroutine uses the training data to check the efficiency of classification algorithm (maximum likely-hood in this case) and presents the data in a tabular form of confusion matrix. Important inputs as mean, covariance matrix and training data itself are transferred to subroutine through labelled common statement. It classifies the training points as belonging to one of the classes from which they are extracted.

STAT04 - this subroutine prepares histograms of brightness value in a band versus frequency for each class. Simultaneously this subroutine plots the histograms on line printer, each '*' representing a single data point.

STAT05 - gives coincident spectral plots in different bands for different classes.

STAT06 - subroutine performs Divergence test for obtaining spectral separability of classes. It tabulates the divergences and transformed divergences along with their average for different band combination. This table serves well for feature selection.

Different possible band combinations and class combinations are generated through subroutine STAT07.

Linkages of these subroutines with either subroutines or main program is shown in Fig (5.1).

5.2 <u>Software for classification algorithm</u> :

This package is used for classification of pixels to one of the predetermined classes. The program BCLASS has the option to use either maximum likelyhood algorithm or Bayes' algorithm, based on a priori probability, if apriori probability for all classes are same the algorithm used is the former one, else the latter one is used. Data input to

main program is a vector of reflectance values from a part of scan line in all four spectral bands. It is retreived from the CCT with help of a subroutine called BCLSO4. The functions performed by other subroutines are as follows -

BCLSO1 - this subroutine performs the statistical analysis of the training data set recorded as a matrix TD. After the statistical operations the mean vector TDMEAN, covariance matrix TDCVAR and inverse covariance matrix are available. Since covariance matrix is not required in the information extraction process and to economize the memory space the inverse covariance matrix is overwritten over the existing covariance matrix TDCVAR. This subroutine also calculates the maximum and minimum of reflectance values in a particular spectral band. All the results of the analysis are transferred to the ready subroutines through common statement.

BCLSO2 - this subroutine is the most important one as it contains the classification algorithm. The input to this subroutine is as a data matrix R that contains the reflectance values of the part of scan line that is to be classified. The probability of a particular pixel to fall within the range of a class(PRO) is calculated and based on this probability the class to which this pixel

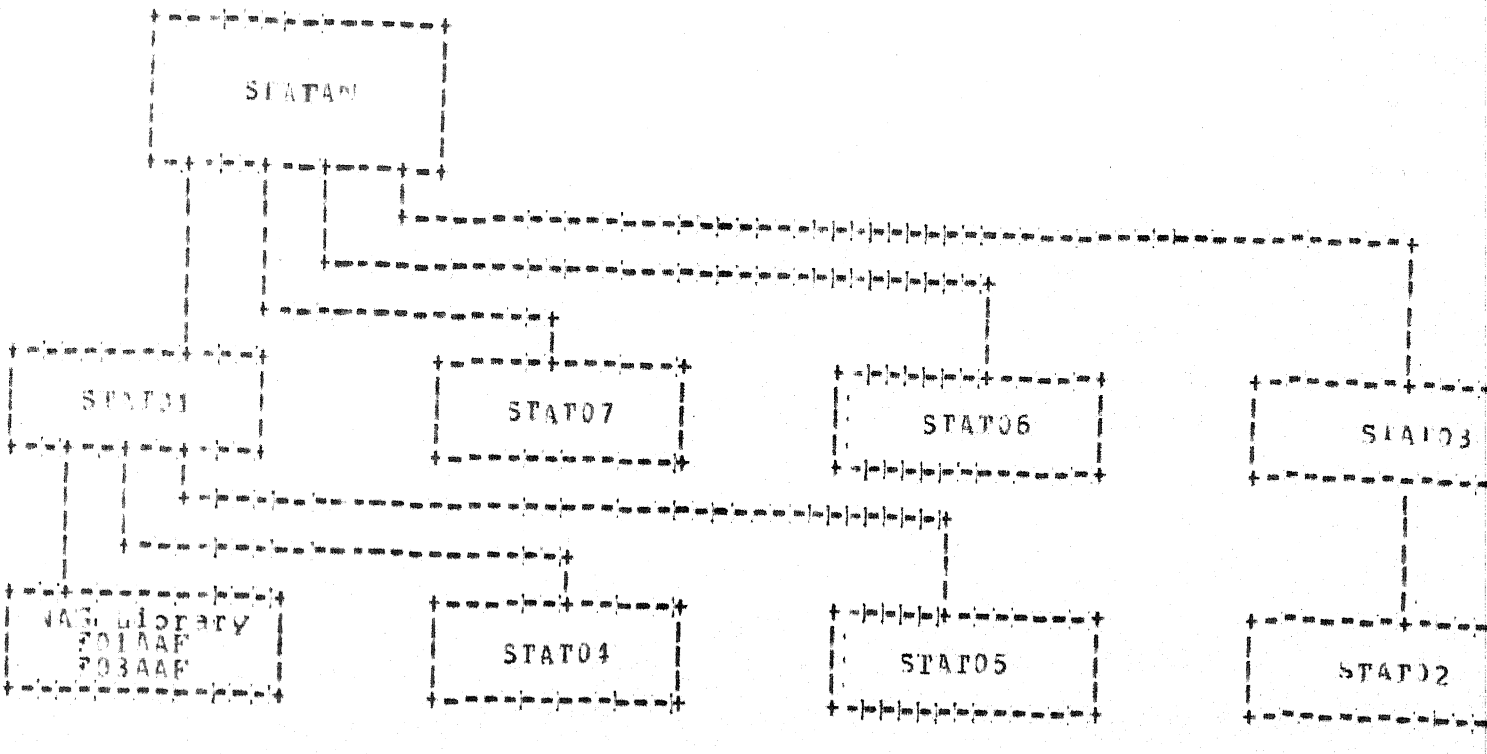

FIGURE 5.1 : Linkage diagram of STATAN.FOR

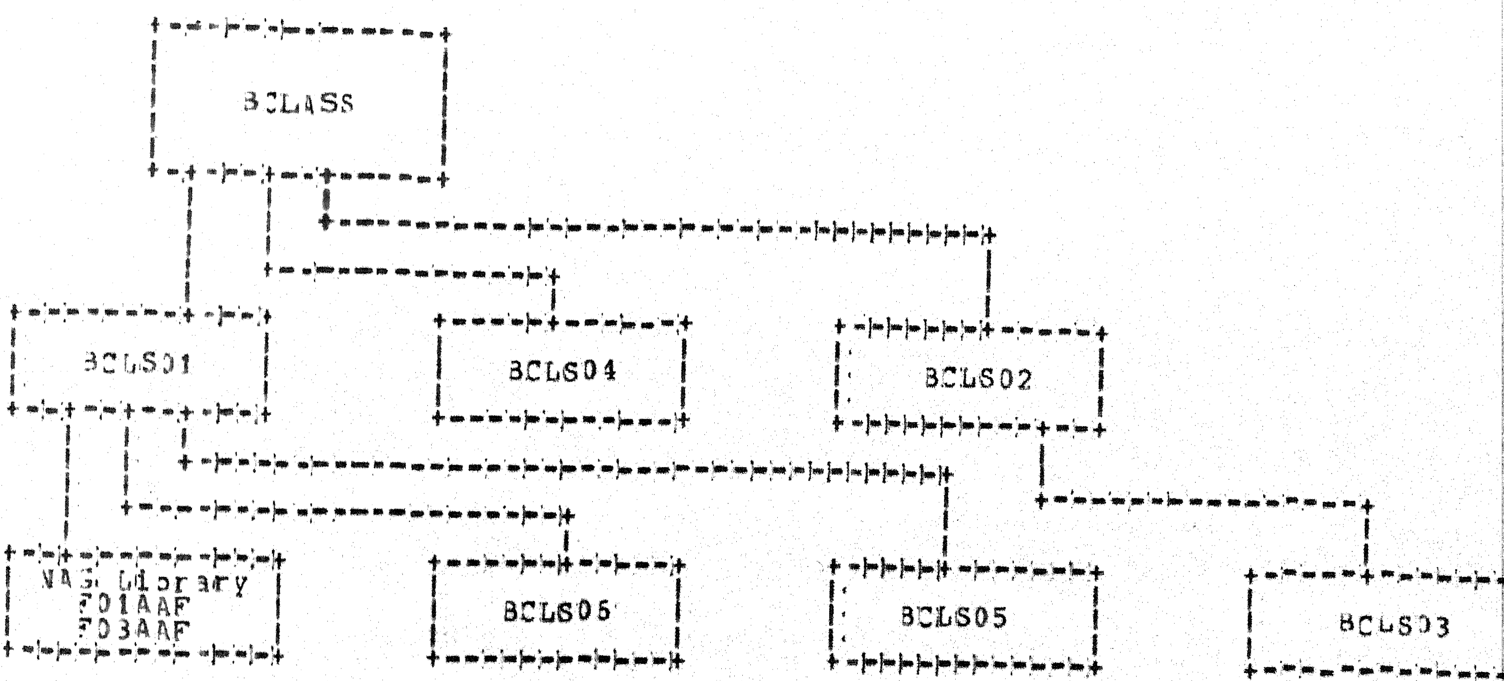

FIGURE 5.2 : Linkage diagram of BCLASS.FOR

represents is decided. A overstruck - characterline - printer land use map is generated in this subroutine only. Subroutine BCLS03 is used in this subroutine for matrix operations.

BCLS04 - this subroutine transfers the required part of four consequentive records ie four bands to subroutine BCLS02. The length of record or the number of pixels to be analysed is given by variable ILENTH. The data on CCT which is in binary mode is changed to decimal system for use in analysis.

Subroutine BCLS05 plots the histograms to check the validity of the assumption pertaining to Gaussian distribution of errors and subroutine BCLS06 gives co-spectral plots to show the expanse of reflectance values in each band for each class.

Subroutine linkage is shown in Fig (5.2).

There are other programs too that were used in the present work. They are described below :

CHPLOT - this program has two options available, the decision is made based on the variable DECIND. If DECIND is 'DEN' this program performs density slicing based on the classes required and their upper and lower

limits. If DECIND is 'HRD' the reflectance value range is divided into sixteen classes and their upper and lower limits are decided by the program. It was used during selection of training data points. The output of this program is generated into output files HRDPn.DAT, where n varies from 1 through 5 depending on the length of record being analysed.

TAPEMR - this program retreives a record from CCT and changes it to decimal mode from the mode of recording ie Binary. It tabulates the reflectance values in classes of class interval of 10. The output is in file REF.DAT.

TMTRNS - this program changes the latitudes and longitudes of a point on ground into line number and pixel number to locate it on the scene. It uses orthomorphic projection.

CHAPTER 6

RESULTS AND DISCUSSION

In this chapter the results obtained from the statistical analysis of training data, the classification of pixels and the field survey are presented. Discussions wherever required are also dealt with. All the presentable results in form of photographs and computer printouts are included in this chapter.

A study of 1:50,000 toposheets of the study area as discussed in chapter one clearly showed the distinctive classes as water bodies, agricultural land, builtup area and barren land. Few of these level I classes were further possible to be separated into level II, For example, water was reclassified into two level II classes based upon the water depth. It was planned initially to separate the Orchards from croplands and pastures to attain level II classification of Agricultural land. But the spectral inseparability of these two level II classes because of coarse resolution of remote sensor data foiled the attempt. Hence the classification achieved was as shown below :

level I	level II
1. Urban or built-up area (incl. roads and railways)	-

level I	level II
2. Agricultural Land	-
5. Water	51. Streams of larger depth
	52. Lakes and streams with less depth water
7. Barren Land	73. Sandy areas by side of the river
	77. mixed barren land not used for agriculture regularly.

6.1 Statistical Analysis :

The statistical analysis results are presented from page to page. Though the tables are self explanatory yet few points need further explaination which will be discussed.

The correlation coefficient calculation between different spectral bands representing a class gives very striking results. It makes note of redundancy of spectral bands in providing further information. For example, in class 1 (Water, 51(USGS)) the coefficients of correlation between bands seven and five (0.66) and bands five and four (0.61) are below 0.95 hence the spectral responses of both the bands in these band sets do not follow the same pattern. It ensures that the different bands produce informations that are complementary to each. It is true for every band for all the classes.

The histogram analysis serves well to check the assumption that distribution of the cloud of points forming the category training data is Gaussian (normally distributed). This assumption of normality is generally reasonable for common spectral response distribution. The histograms for all the bands are Gaussian in nature, though the spread and location characterised by variance and mean values of brightness DN are different for each histogram.

Coincident spectral plot is another way to present the training data. The spread of brightness values for training points in each class are present for each spectral band. The overlap of these spectral plots for different classes may hint that the separability of the classes whose cospectral plots overlap is poor in that particular band. For example, in band 4, the separability of classes builtup area (represented as 3) and cultivated area (represented as 4) and builtup area and water of less depth (represented as 5th class) are questionable. Similarly spectral plot for sandy area (represented as class 2) and cultivated area overlap in all the four spectral plots, 100% overlap being in band 7. But this plot alone

can not be the confirmatory statement about the spectral separability. We will have to go for divergence test to ensure the separability of classes.

The divergence and transformed divergence test is conducted for two purposes, namely (1) separability of different classes and (2) most optimum band combination for classification algorithm, ie feature selection. The test conducted for the first purpose helped in a way that it told in advance that further classification of agricultural land in level II classes of cultivated land (represented as class 4) and orchards (represented as class 6) is not possible as their divergence is well below the recommended limit of 1500.

The feature selection is the selection of spectral bands (features) be used in classification to give best results in least of computational effort. The different band combinations (equal to 15) are generated in program STATAN. For each band combination the divergences were calculated for all possible class pairs. The average divergence for each band combination was calculated at the same time. This average divergence gives a measure of utility of that particular band combination as the

features in classification process. Eg. the combination of all the four bands give the maximum of average transformed divergence hence can be used with greatest reliability in class separation. At this point it should be emphasised that higher number of bands used in classification do not always ensure better results in terms of separation of classes. For example, band 7 alone gives better separability when compared to bands 4 and 5 or 4 and 6 are being used in divergence test.

Expressions used for calculations of divergence and transformed divergence are different and so are the acceptable limits to classify two classes as distinct classes. But it seems the limit of 1500 for divergence tends to give very conservative limit. Hence transformed divergence is very appropriate to be used because the limits are in accordance to the results obtained.

6.2 Land Use Map :

The land-use map prepared in the program BCLASS is in fact a mosaic prepared from separate computer print outs. Each computer printout consists of an overstruck-character representation of (120x79) pixels. Six such

sheets were pasted to get a mosaic and four such mosaics covered whole of the study area. The relative positions of mosaics, identified as A,B,C and D, are represented in Fig (6.1). A mosaic wise discussion of them is given in one of the following sections.

6.3 Field Survey :

To check the accuracy of prepared land use map an extensive field survey was conducted. 'Ground truths' were collected during this survey. This survey was carried out in month of March. The data collected during this period is given in table form. This data was compared with the one furnished by the assumed land use map and a contingency table was calculated to give the accuracy in percentage for different classes. The table is given in Table (5.2).

6.4 Discussion over the land Use Map - Moosaic A :

The most strickingly identifiable pattern on this mosaic is the meander of river Gomati. Most of the area covered is cultivated, with study patches of builtup areas. The course of river has not changed much since 1972, the year in which the Survey of India released the toposheet of the area. This statement is supported by the prepared

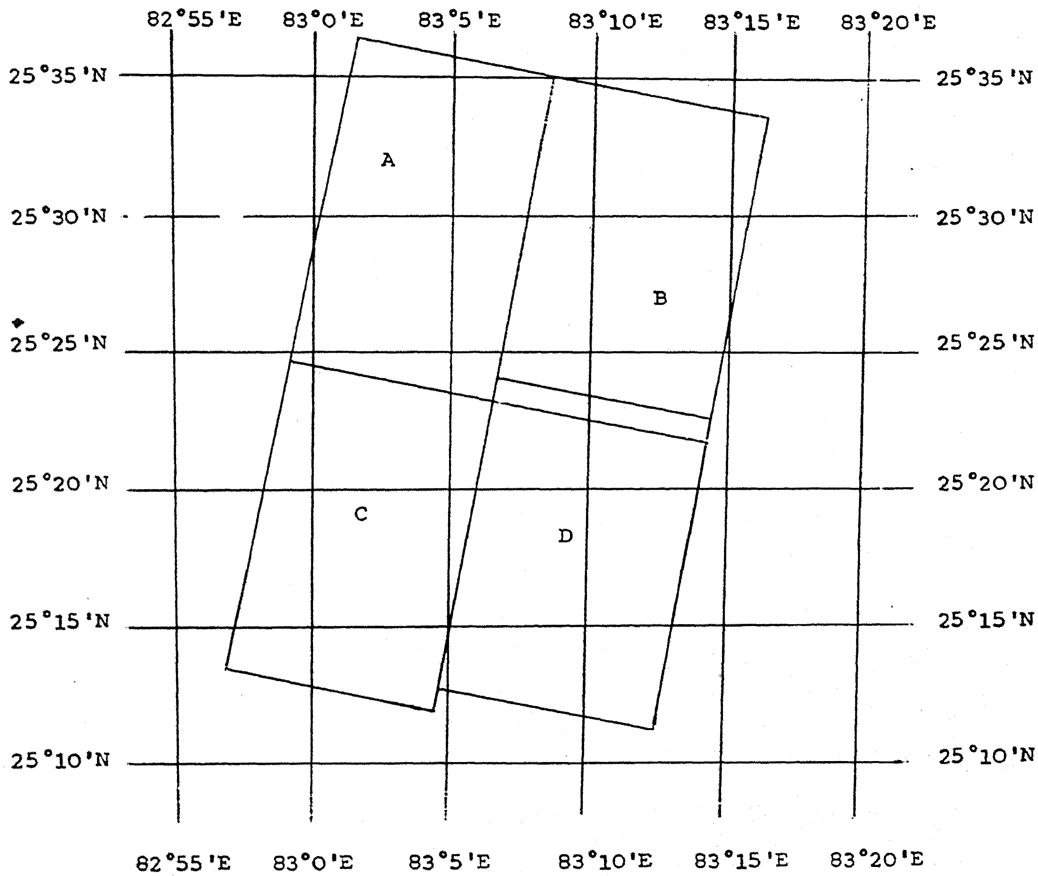

Fig. 6.1 : Location of Mosaics.

land use map as well as the 'ground truth' survey. The sand bar from line number 1859 pixel number 1570 to line number 1864 pixel number 1545 is a recent feature not depicted in toposheets. It seems that during high discharge season a subsidiary channel traversed the path and dried after recession of floods leaving the existing sand bar. At most of the places the builtup area was correctly mapped (4 out of 5 sites). The land use map shows patches of sand in between agricultural land. Certainly, it is very unlikely that sand be there, hence few such sites were visited during the field survey. It was found that these parts of land have not been used for agricultural purposes for many years because of its poor productivity. Not tilling the land for many years compacted the soil and the compacted soil, which is supposed to has the same spectral response as dense sand was classified as sand. Though this class of unproductive land was not taken into consideration initially while selecting training data set, it was accepted as a separate class after the field survey. The deeper water of river Ganga is rightly classified and shown in middle of right hand side of the mosaic. The road (NH29) and railway line (NE Railway:Chhapra, Varanasi, Allahabad Branch) could not be classified because of

coarse resolution of Landsat. No identifiable growth of built up area took place in concerned area.

Mosaic B -

This mosaic covers parts of Varanasi and Ghazipur districts. The curvilinear pattern of the river Ganga is very truthfully reproduced in land use map in accordance with what is there in the toposheet (SOI, 63 O/3) except slight changes in the shape of the sand islands in river water. The size of sand island (line number 1931 pixel number 1670) has grown bigger as compared to one given in the toposheet due to deposition. Similarly the shape of the sand island (line number 1970 pixel number 1746) had also changed. The builtup area shown here and there on the islands are the constructed banks (ghats).

The change in builtup area is very preminent in this mosaic when compared to the status in 1972. Two towns have shown noticeable growth in builtup area - (1) Shivdaspur Gangabarar (line number 1950; pixel number 1665) and (2) Jura Hardhan (line number 1887 pixel number 1705). Chanda Tal which is mudy pend is also clearly classified as less depth water class (line number 1890 pixel number 1709). Sometimes roads and railway lines, inspite of their thickness less than the spatial resolution

of MSS, appear very clearly. It is because of the builtup area coming up along the roads and railway lines. They show a distinctive linear pattern of builtup areas as is evident from line number 1803 pixel number 1756 to line number 1879 pixel number 1826.

There is a striking change in confluence point of river Gomati and river Ganga. As the toposheet 63 $\frac{O}{2}$ shows that the confluence of these two rivers was at Saidpur (line number 1790 pixel number 1691) in 1972. But the land use map that was prepared showed a deviation of confluence to a point upstream (line number 1829 pixel number 1670). The results of field survey will be present later on.

Mosaic C -

This mosaic consists of land use map covering most of Varanasi city. Again the river Ganga is very prominentely and accurately mapped. The meander patterns remained same atleast for last 16 years, only the shape and size of sand bars have changed. To the west of river Ganga lies the city whose northern limit is the river Varuna. The accuracy with which the city is mapped is more than agreeable. It was checked during field survey. The confluence of river Varuna with river Ganga could not be mapped probably owing to its small thickness.

On the east of river Ganga lies small towns as Bahadurpur (line number 2097 pixel number 1553), Ramnagar (line number 2155 pixel number 1540), Shahapuri colony (pixel number 1599 line number 2135) and villages as Semra (line number 2128 pixel number 1516), Domri (line number 2115 pixel number 1522) etc. The map also contains Grand Trunk road and NE Railway main line because they appear continuously in many pixels. The GT road is the upper diagonal line and NER main line is the lower diagonal line in the right half of the map. Pond near Wajidpur (line number 2149 pixel number 1545) is also rightly classified as water of less depth.

The boom of development of builtup area is felt in locality covering towns Kunda Kalan, Bhawanipur, Naria (line number 2093 pixel number 1600). It was found to be true during the field survey.

Mosaic D -

This mosaic covers the town of Mughal Sarai. In the upper part of mosaic bend of river Ganga is shown along with a low discharge channel separating from the same known as Sota nala, which takes a turn in S shape to meet the main branch of Ganga river. The builtup

area near Jalupur (line number 2004 pixel number 1677) showed an increase. In Mughal Sarai NR main line meets the NR main line (Electrified). This clusturing of railway line produces a misleading classification. The reflectance values purely from a railway track seems to be lower when compared to the same of built up area or cultivated land. Where there is a single track the spectral response, recorded for a pixel covering that area, is governed mostly by spectral response of cultivated land and/or built up area close to railway track and that pixel is classified as either built up area or cultivated land. But the responses for pixels representing multitrack patch of land, the responses of railway line predominate. Since the brightness values of railway track are low as compared to that of built up area, such pixels representing multi-track railway lines are classified into a class that has a lower brightness DN as compared to that of built up area ie water of less depth. This misclassification arises out of the fact that less number of classes, to which a pixel is to be assigned, are considered because of following two facts - (1) the resolution of MSS is coarse hence one can not always expect to discriminate all the classes present on the ground and (2) un-

availability of detailed (large scale) maps for selection of training data points for all the classes. Similar phenomenon of misclassification occured in mosaic C also. Grand Trunk Road (NH2) is very clearly mapped in the mosaic D. Built up areas have started coming up in surroundings of Shivadasa Gangbarar (pixel number 1670, line number 1945).

6.5 Accuracy Assesment :

Based on field survey contingency table (Table 6.2) was prepared for accuracy assesment. Both the errors - errors of omission and error of commission, are calculated. The table is self explainatory. The accuracy is given as percentage.

6.6 Conclusion :

The automated digital approach to land use map preparation is a worth while process, in sense that the whole process starting from the data acquisition, data correction and information extraction finishes in a short time span. Where as the traditional methods of ground surveys and map preparation takes as much as two years. Another benefit that can be incurred from the use of satellite plateforms is the fast and repetive data about the land cover and land use. The use of MSS landsat

data with a coarse resolution of 80 m have given a tolerable accuracy, few of the level II classes were also effeciently classified. Four land use classes namely water, compacted sand, agricultural land, and built up area with further classification of class water in two level II classes has been achieved.

6.7 Further Recommendations :

The resolution of Landsat MSS is about 80 m. With such coarse resolution the classification at level II is not very fruitful. Thus good resolution data as from Landsat TM or SPOT should be used for effective and reliable level II classification.

The spatial change in the land use pattern over a span of time can be studied, if landsat data are available at two times. This study should be conducted in future by someone interested; by acquiring a new landsat imagery of same area.

Table 6.1 : Ground Truth Survey results.

S. No.	Site visited	location	land use class on site	land use class on map	Remarks
1	2	3	4	5	6
A	Malahia	25°14'50"N 83° 1'25"E			
1			1	1	Correct classif
2			2	2	Correct classif
B	Madarwa	25°15'16"N 83° 1'10"E			
3			1	1	Correct classif
4			73	2	Wrong classif
5			2	2	Correct classif
C	Bhogpura	25°17' 0"N 83° 0'10"E			
6			1	1	Correct classif
7			2	1	Wrong classif
D	Bhelupura	25°17'30"N 83° 0'20"E			
8			1	1	Correct classif
9			51	51	Correct classif
10			73	73	Correct classif
E	Sarian	25°20' 3"N 83° 1'27"E			
11			52	52	Correct classif
12			2	2	Correct classif
13			1	52	Wrong classif
14			1	1	Correct classif
F	Delwaria	25°20'25"N 83° 0'10"E			
15			1	1	Correct classif
16			2	1	Wrong classif
17			52	1	Wrong classif
G	Semari	25°17'50"N 83° 2'17"E			
18			1	1	Correct classif
19			2	2	Correct classif
20			73	73	Correct classif
21			51	51	Correct classif

(contd...)

1	2	3	4	5	6
H	Jalilpur	25°18'15"N 83° 3' E			
22			1	1	Correct classif
23			1	52	Wrong classif
24			2	2	Correct classif
25			52	52	Correct classif
I	Ramnagar	25°16'20"N 83° 2' 5"E			
26			1	1	Correct classif
27			1	1	"
28			2	2	"
29			2	2	"
30			52	52	"
J	Sholapur	25°16' N 83° 4'10"E			
31			1	1	"
32			2	2	"
33			2	52	Wrong classif
34			77	77	Correct classif
35			2	77	Wrong classif
K	MughalSarai	25°15'10"N 83° 5'12"E			
36			1	1	Correct classif
37			2	1	Wrong classif
38			2	1	Correct classif
39			1	52	Wrong classif
40			52	52	Correct classif
41			1	77	Wrong classif
42			77	77	Correct classif
43			1	2	Wrong classif
44			77	77	Correct classif
L	Salinabad	25°19' 5"N 83°10'10"E			
45			1	2	Wrong classif
46			2	2	Correct classif
47			1	1	Correct classif

(contd...)

1	2	3	4	5	6
M	Daurikot	25°16' 3"N 83°14' E			
48			1	1	Correct classif
49			2	2	Correct classif
50			52	2	Wrong classif
N	Gokulpura	25°19'40"N 83° 9'35"E			
51			51	51	Correct classif
52			52	52	"
53			2	2	"
54			73	73	"
56			52	52	"
O	Ramgarha	25°25'10"N 83° 3'20"E			
57			1	1	Correct classif
58			2	2	"
59			77	2	Wrong classif
60			77	77	Correct classif
61			52	2	Wrong classif
P	Sarnath	25°18'10"N 83° 2' 0"E			
62			1	1	Correct classif
63			1	1	"
64			2	2	"
65			2	77	Wrong classif
66			77	77	Correct classif
Q	Dasawatpur	25°27'15"N 83° 2' 5"E			
67			1	2	Wrong classif
68			2	2	Correct classif
69			2	77	Wrong classif
70			77	2	Wrong classif
71			77	77	Correct classif
R	Raunan Khurd	25°27'45"N 83° 2'30"E			
72			2	2	Correct classif
73			2	2	"
74			2	2	"

(contd...)

1	2	3	4	5	6
75			2	2	Correct
76			77	77	"
77			77	77	"
S	Daurahara	25°30'10"N 83° 6' 5"E			
78			1	1	Correct
79			2	2	"
80			77	77	"
81			52	52	"
82			52	52	"
T	Jura Hard-han	25°22'30"N 83°11'00"E			
83			1	1	Correct
84			1	1	"
85			52	52	"
86			77	77	"
87			2	77	Wrong
88			1	2	"
89			77	2	"
U	Pura Bijai	25°22'30"N 83°10'10"E			
90			1	1	Correct
91			51	51	"
92			52	52	"
93			52	52	"
94			1	2	Wrong
V	Mahawari	25°24' 5"N 83°11'10"E			
95			1	1	Correct
96			2	2	"
97			51	51	"
98			73	73	"
99			73	2	Wrong
100			52	52	Correct
101			1	1	"
W	Misirpur	25°24'45"N 83° 9'40"E			
102			1	2	Wrong classif

(contd....)

1	2	3	4	5	6
103			52	52	Correct
104			2	2	"
105			51	51	"
106			73	73	"
X	Ajgara	25°28'30"N 83°12'15"E			
107			1	1	Correct
108			1	2	"
109			52	2	Wrong
110			2	2	Correct
111			2	77	Wrong
112			77	77	Correct
113			1	1	"
Y	Tanda Kalan	25°30' 0"N 83°10' 5"E			
114			1	1	"
115			73	73	"
116			51	51	"
117			2	2	"
118			2	2	"
119			52	52	"
120			73	73	"
Z	Saidpura	25°32' 5"N 83°16' 0"E			
121			1	1	"
122			51	51	"
123			51	51	"
124			52	52	"
125			2	77	Wrong
126			77	77	Correct
127			2	77	Wrong

	(1)	(2)	(52)	(51)	(73)	(77)	Total	Error of Omission	Error or Commission
Built up Area (1)	27	7	3	-	-	1	38	29%	12.9%
Cultivated Area (2)	3	25	1	-	-	7	36	30.6%	37.5%
Water of less depth (52)	1	3	15	-	-	-	19	21.1%	21.1%
Deep Water (51)	-	-	-	9	-	-	9	0%	0%
Sandy Area (73)	-	2	-	-	7	-	9	22.3%	0%
Barren land (77)	-	3	-	-	-	13	16	18.8%	38.1%
Total	31	40	19	9	7	21	127	Percentage accuracy 75%	

APPENDIX TO CHAPTER 6

This appendix contains the mosaic prepared for the study area and results of Image processing of the digitized data for the same.

Plate 1 : shows the image of the Band 7 data. Since the Brightness values were recorded from 6 to 130, hence does not use the full range available on IP system, ie 0 to 255. It is the reason for its poor contrast result.

Plate 2 : shows a stretched image of a part of the scene in band 5. The clearity of the image shows the advantage of image stretching over unstretched one (as in plate 1).

Plate 3 : is a result of superposition of stretched data in three different bands, ie band 4, band 5 and band 7. It is zoomed to bring out certain features which were not identified on the line-printer map because of poor resolution; but the spectral resolution as well as the spatial resolution of IP system being good, it brought out many features prominently as the roads, railways etc.

Plate 4 : it is again a zoomed, superimposed and stretched image in three channels. Blue colour represents deep waters as in river along its centre line and few ponds. Grayish

red shows the cultivated area when as red channel represents sand bars and unused barren land. Black colour represents water of less depth as well as the built up area, because it is not possible with eyes alone to differentiate between slightly varying tone of these two classes. The green colour represents the built up area made out of mud and thatch that have less reflectance as compared to the concrete or ~~masionary~~ masonary structure.

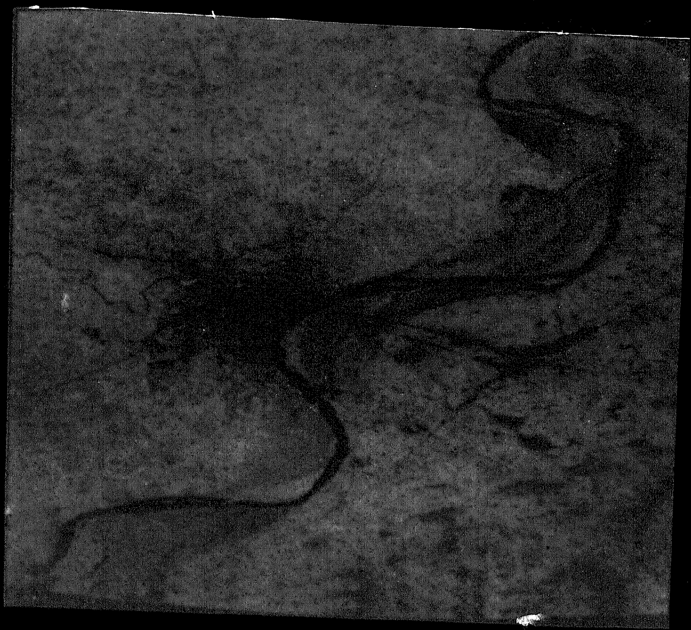

Plate 01

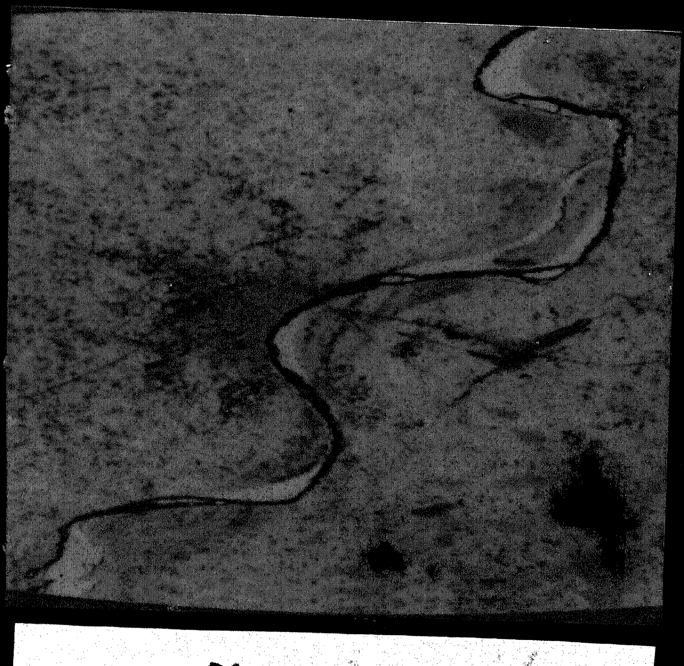

Plate 02

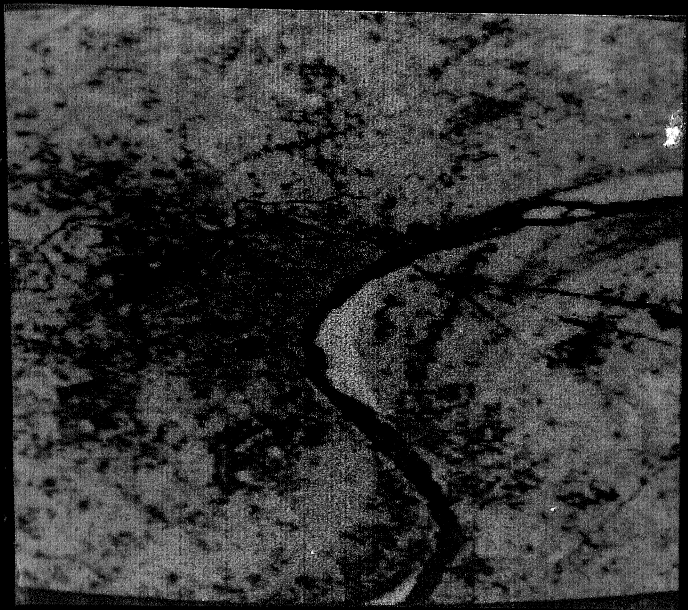

Plate 03

Plate 04

Statistics for class 1 (DEEP WATER)

Band :	4	5	6	7
Mean	43.30	38.75	15.28	17.85
Variance	8.78	7.27	10.00	5.25
Minimum	39	33	8	12
Maximum	52	44	21	23

Variance Covariance matrix

Band 4	8.78			
Band 5	4.90	7.27		
Band 6	3.56	4.04	10.00	
Band 7	1.92	4.09	3.91	5.25

Inverse Variance Covariance matrix

Band 4	0.20			
Band 5	-0.16	0.38		
Band 6	-0.04	-0.00	0.15	
Band 7	0.08	-0.23	-0.10	0.41

Correlation coefficients

Band 4	1.00			
Band 5	0.61	1.00		
Band 6	0.39	0.47	1.00	
Band 7	0.28	0.66	0.54	1.00

Statistics for class 2 (BARREN LAND)

Band :	4	5	6	7
Mean	115.38	115.15	132.42	87.43
Variance	25.30	25.82	15.23	4.51
Minimum	1[illegible]3	101	120	83
Maximum	125	124	145	91

Variance Covariance matrix

Band 4	25.30			
Band 5	1[illegible].12	25.82		
Band 6	1[illegible].35	5.27	15.23	
Band 7	0.33	2.29	2.72	4.51

Inverse Variance Covariance matrix

Band 4	0.06			
Band 5	-0.02	0.05		
Band 6	-0.04	-0.00	0.10	
Band 7	0.03	-0.02	-0.06	0.27

Correlation coefficients

Band 4	1.00			
Band 5	0.38	1.00		
Band 6	0.51	0.27	1.00	
Band 7	0.03	0.21	0.33	1.00

Statistics for class 3 (BUILT-UP AREA)

Band :	4	5	6	7
Mean	71.98	71.85	89.43	58.65
Variance	42.08	24.03	34.10	15.69
Minimum	57	60	75	59
Maximum	97	87	98	75

Variance Covariance matrix

Band 4	42.08			
Band 5	22.87	24.03		
Band 6	11.70	8.71	34.10	
Band 7	-5.56	0.69	7.20	15.69

Inverse Variance Covariance matrix

Band 4	0.06			
Band 5	-0.06	0.10		
Band 6	-0.01	0.00	0.04	
Band 7	0.03	-0.03	-0.02	0.03

Correlation coefficients

Band 4	1.00			
Band 5	0.72	1.00		
Band 6	0.31	0.30	1.00	
Band 7	-0.25	0.03	0.30	1.00

Statistics for class 4 (AGRICULTURAL AREA)

Band :	4	5	6	7
Mean	91.98	92.85	118.72	91.28
Variance	50.33	29.00	130.20	151.87
Minimum	81	84	95	73
Maximum	111	105	139	127

Variance Covariance matrix

Band 4	50.33			
Band 5	7.07	29.00		
Band 6	45.76	28.39	130.20	
Band 7	11.50	16.42	-44.78	151.87

Inverse Variance Covariance matrix

Band 4	0.04			
Band 5	0.02	0.07		
Band 6	-0.02	-0.03	0.03	
Band 7	-0.01	-0.02	0.01	0.01

Correlation coefficients

Band 4	1.00			
Band 5	0.19	1.00		
Band 6	0.58	0.46	1.00	
Band 7	0.13	0.25	-0.32	1.00

Statistics for class 5 (LESS DEEP WATER)

Band :	4	5	6	7
Mean	61.10	55.08	60.15	37.90
Variance	59.02	25.10	254.85	51.68
Minimum	47	46	38	25
Maximum	76	68	95	49

Variance Covariance matrix

Band 4	59.02			
Band 5	-14.26	25.10		
Band 6	87.34	-39.60	254.85	
Band 7	-19.34	20.42	-38.04	51.68

Inverse Variance Covariance matrix

Band 4	0.04			
Band 5	-0.00	0.07		
Band 6	-0.01	0.01	0.01	
Band 7	0.01	-0.02	-0.00	0.03

Correlation coefficients

Band 4	1.00			
Band 5	-0.37	1.00		
Band 6	0.71	-0.50	1.00	
Band 7	-0.36	0.57	-0.33	1.00

HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS

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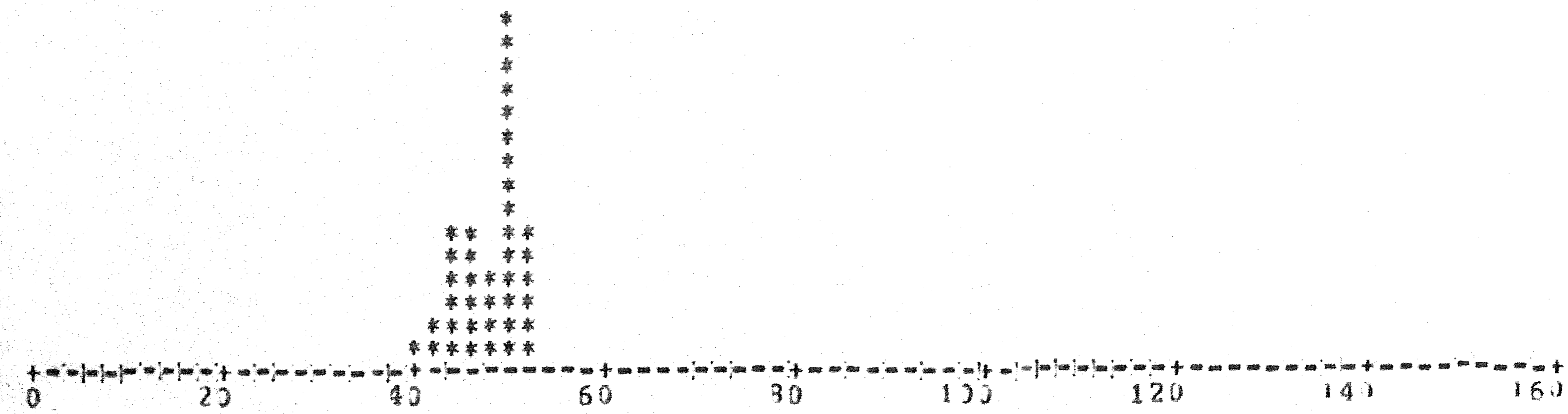

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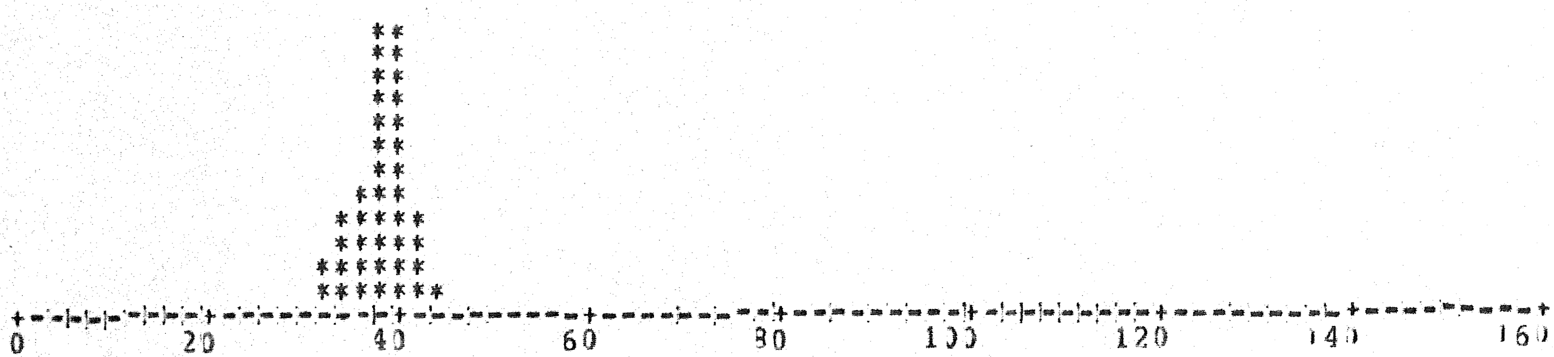

HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS   Continued.....

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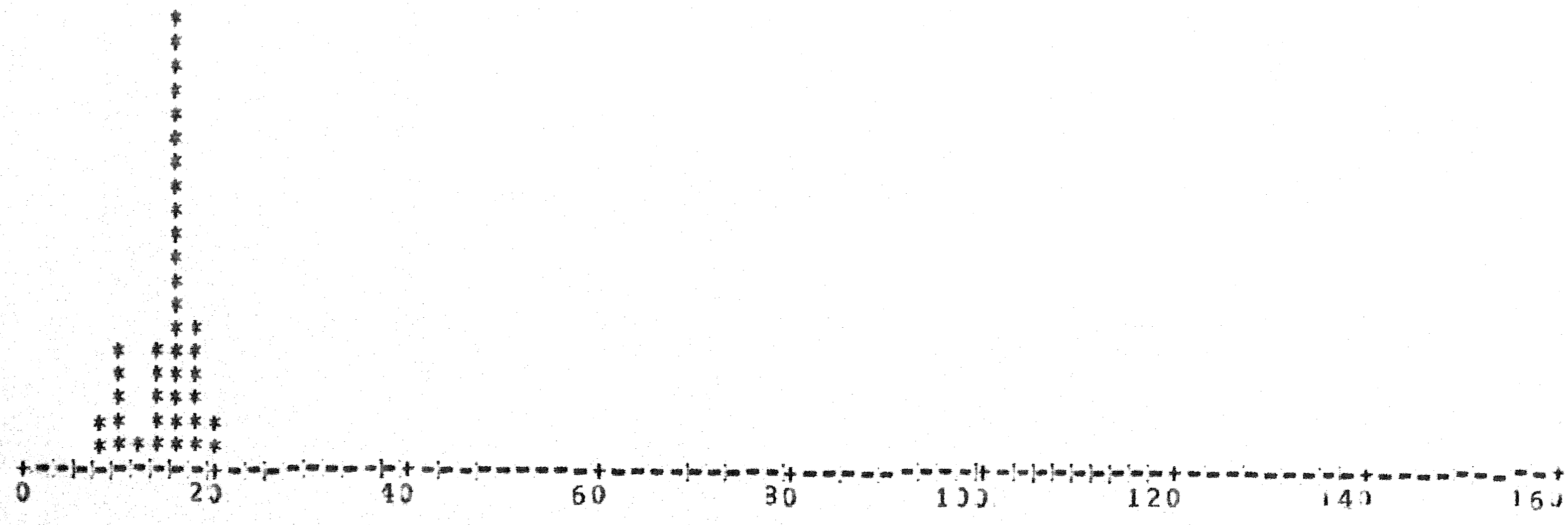

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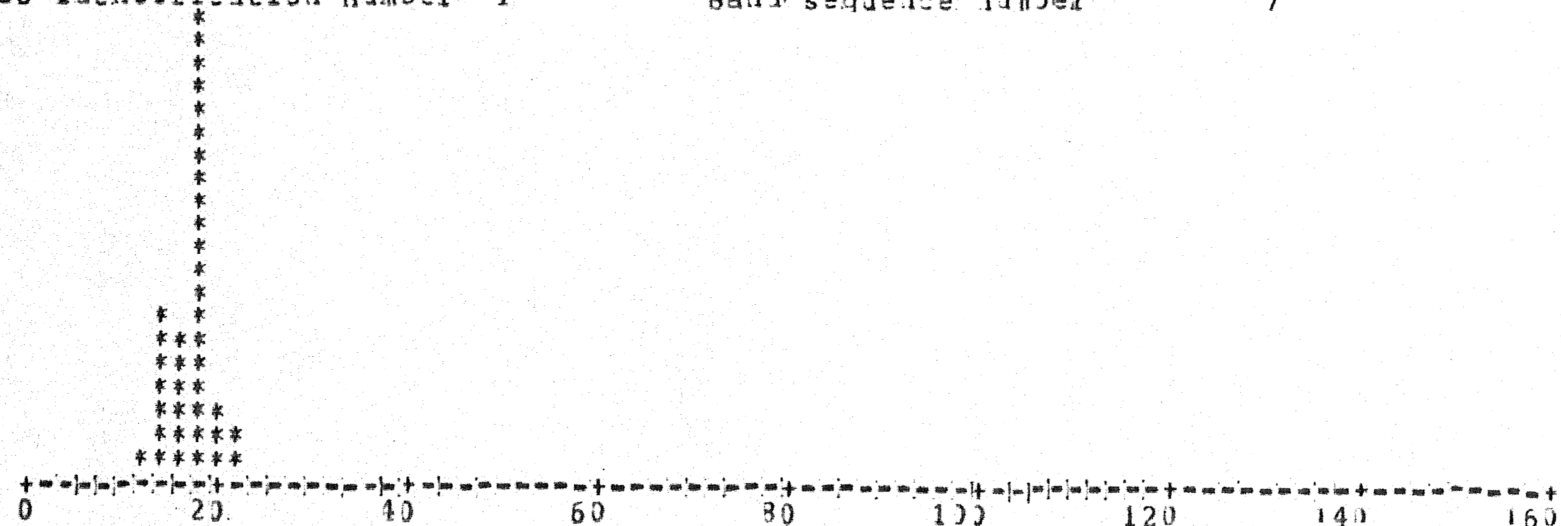

HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS   Continued.....

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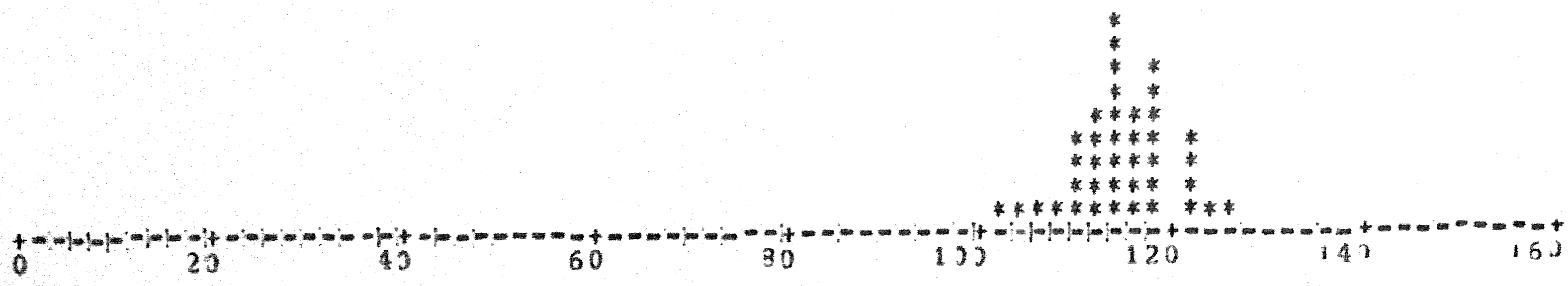

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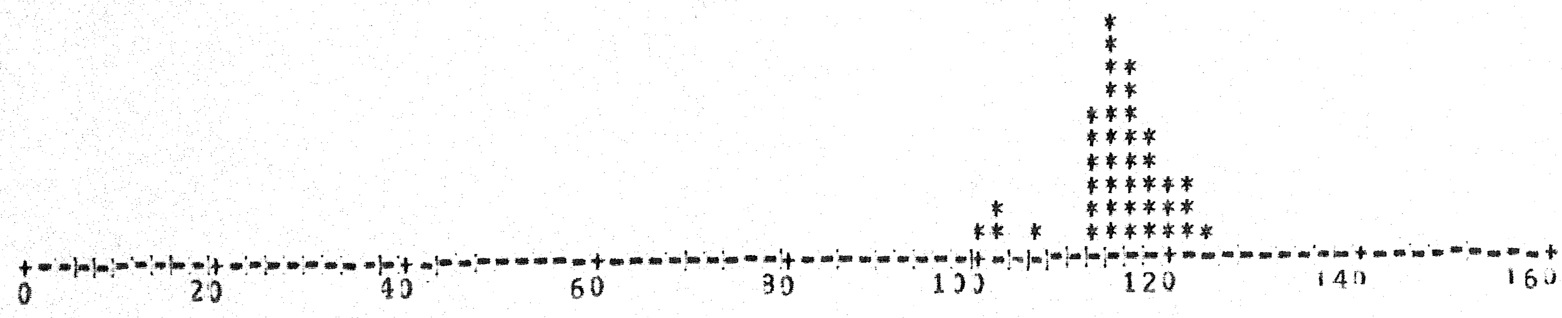

HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS   Continued......

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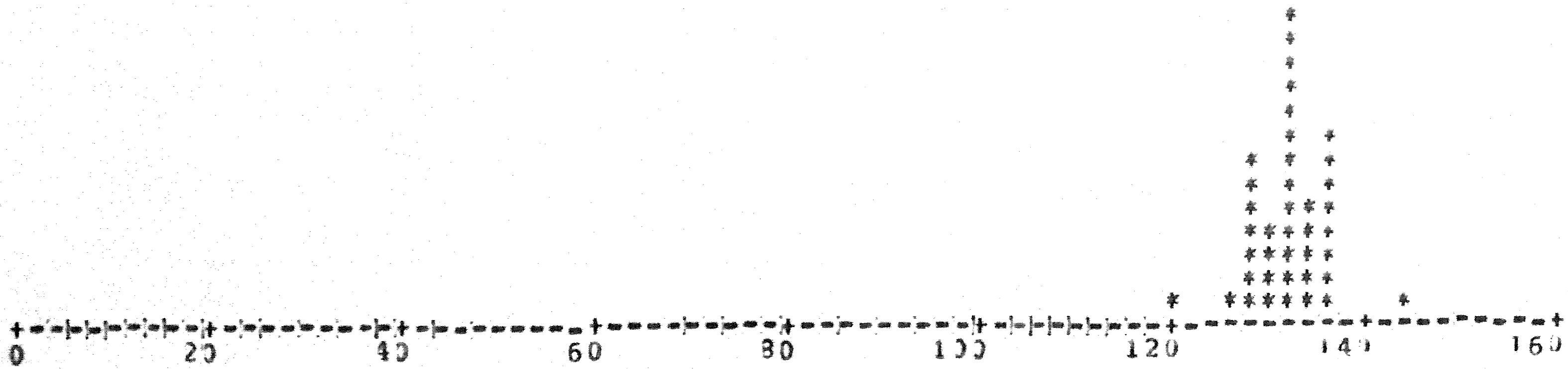
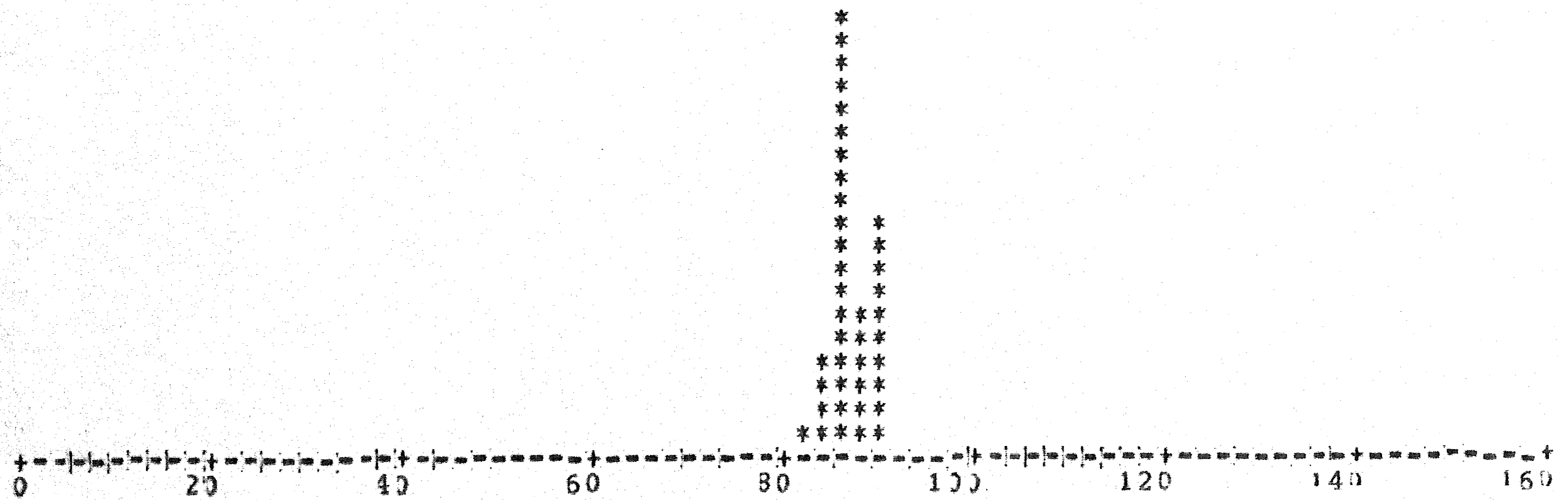


Class identification number 2   Band sequence number 7



HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS Continued......

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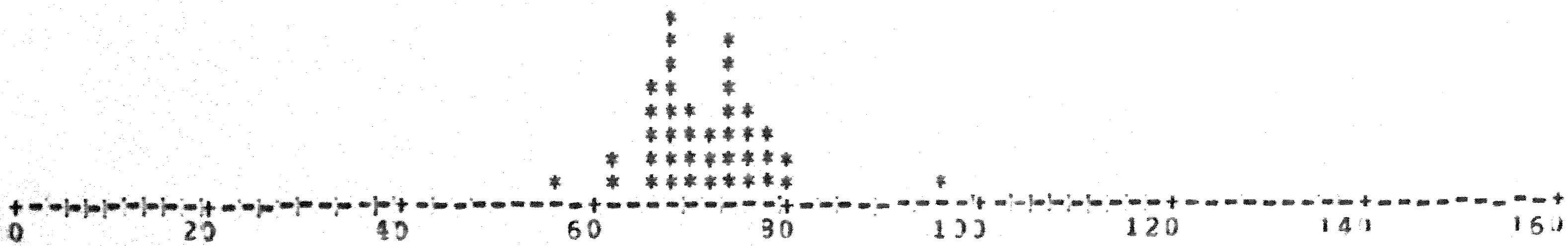
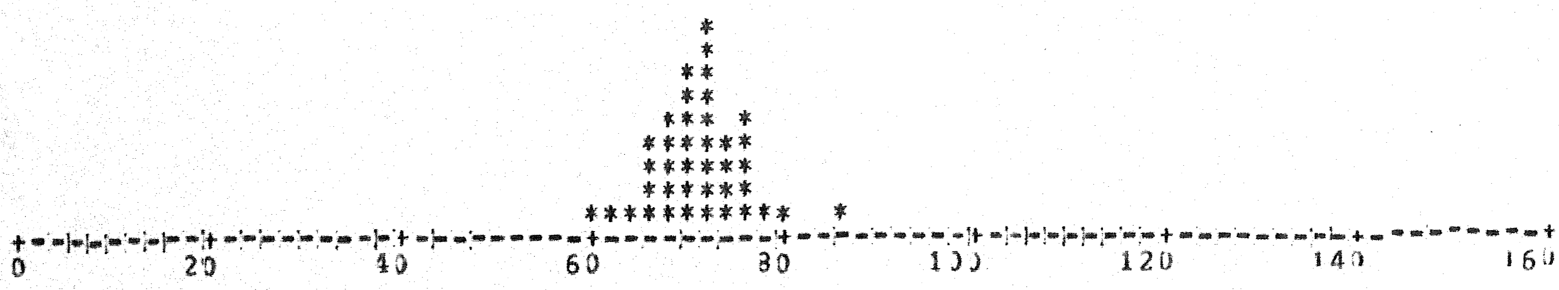


Class identification number 3 Band sequence number 5



HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS   Continued.....

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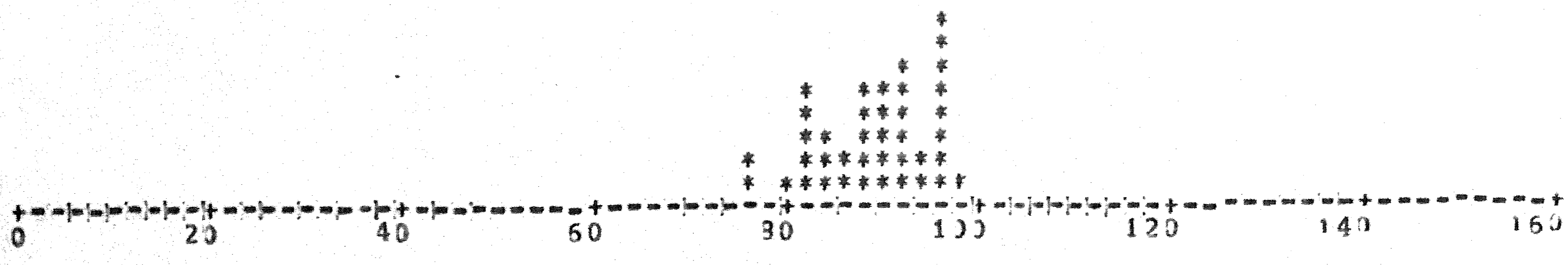
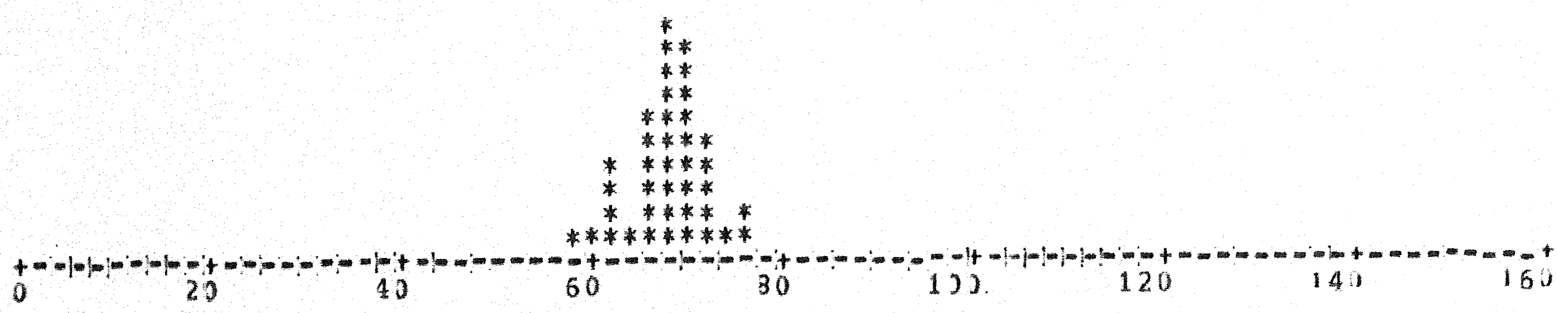


Class identification number 3   Band sequence number 7



HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS Continued.....

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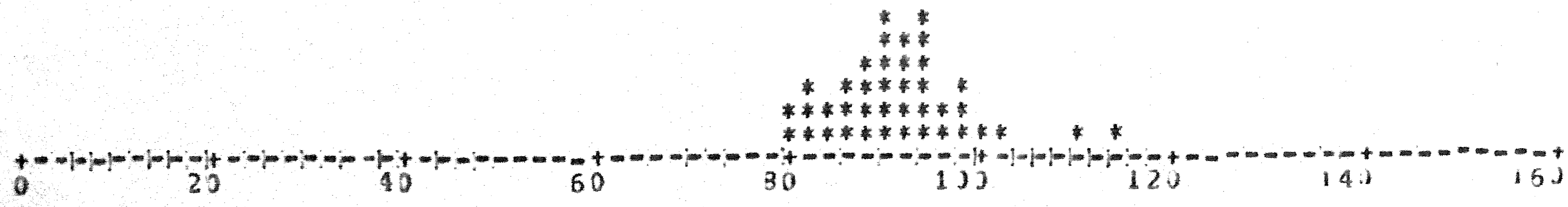
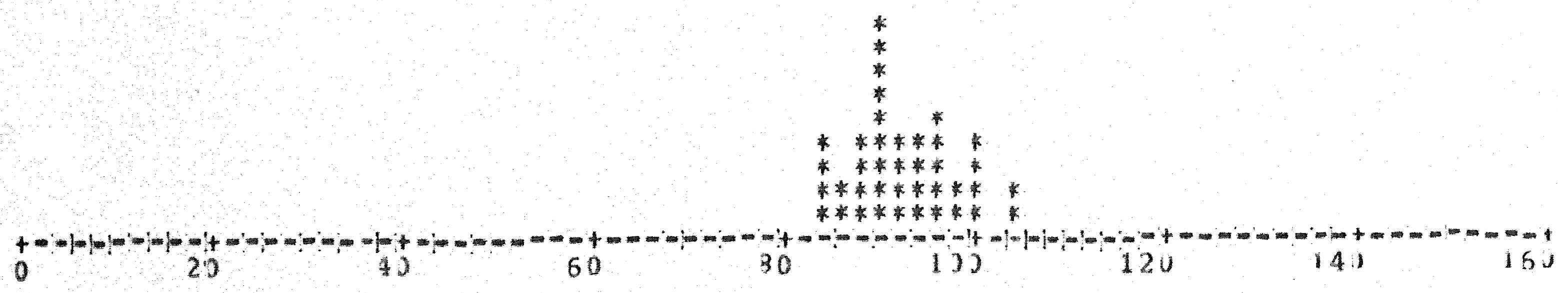
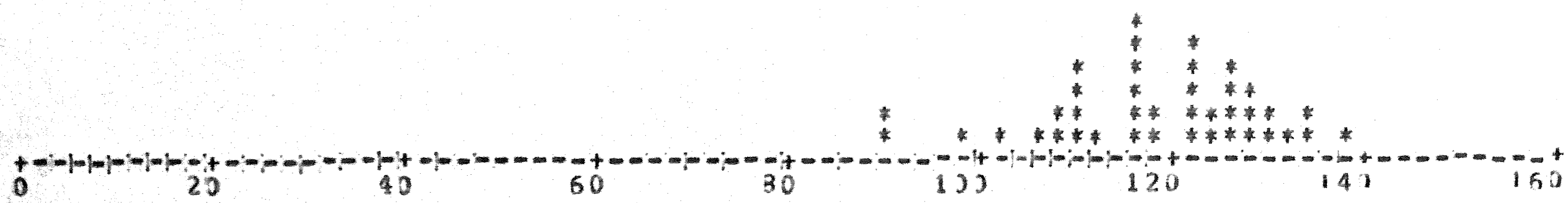


Class identification number 4 Band sequence number 5

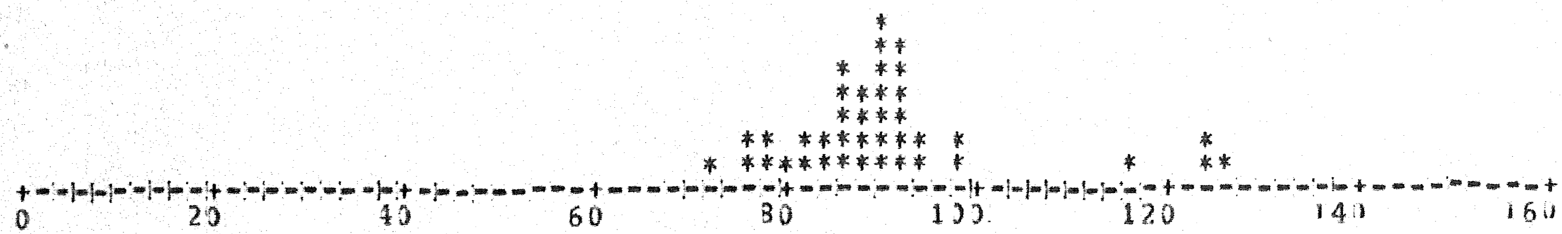


HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS   Continued.....

Class identification number 4   Band sequence number 6

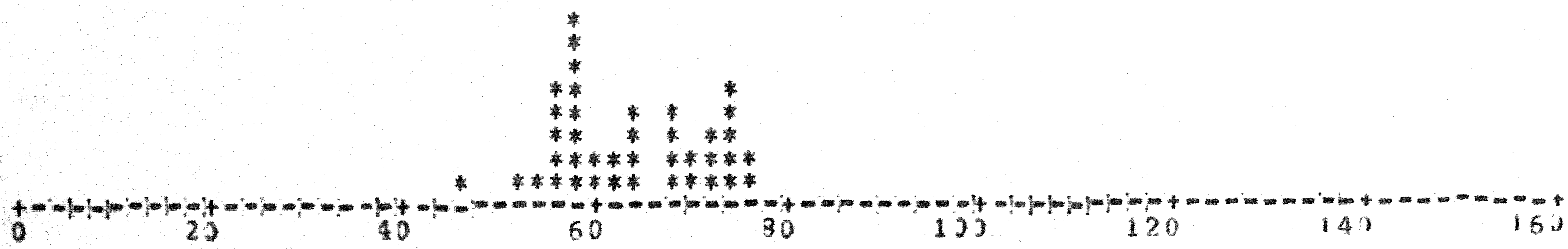


Class identification number 4   Band sequence number 7

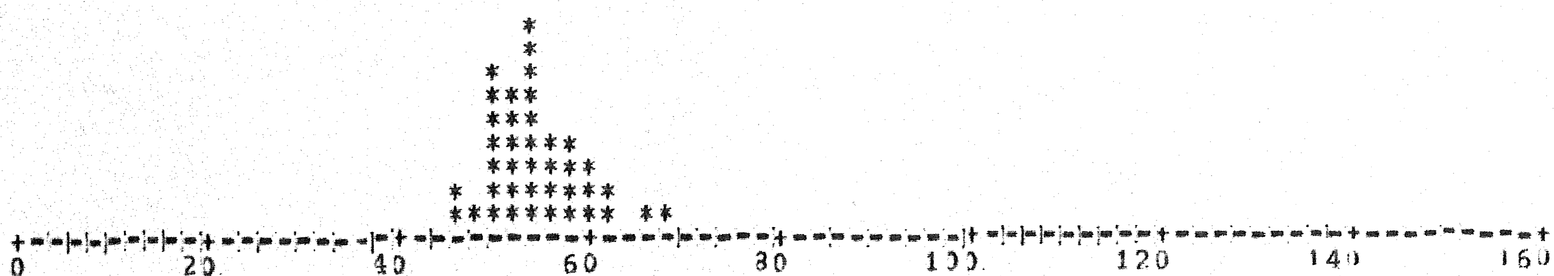


HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS Continued.....

Class identification number 5 Band sequence number 4

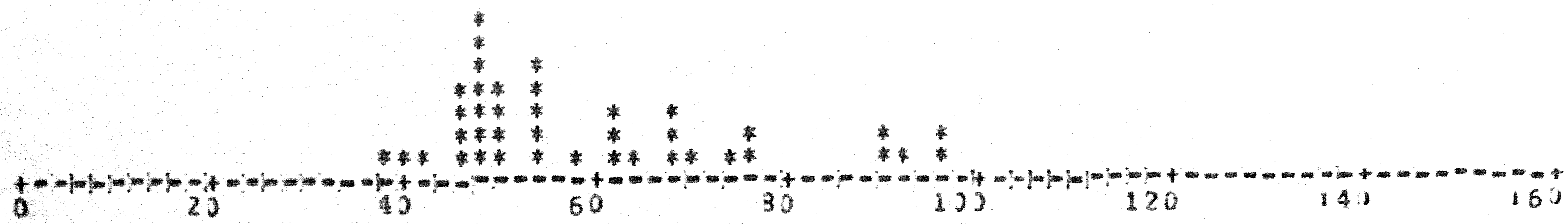


Class identification number 5 Band sequence number 5

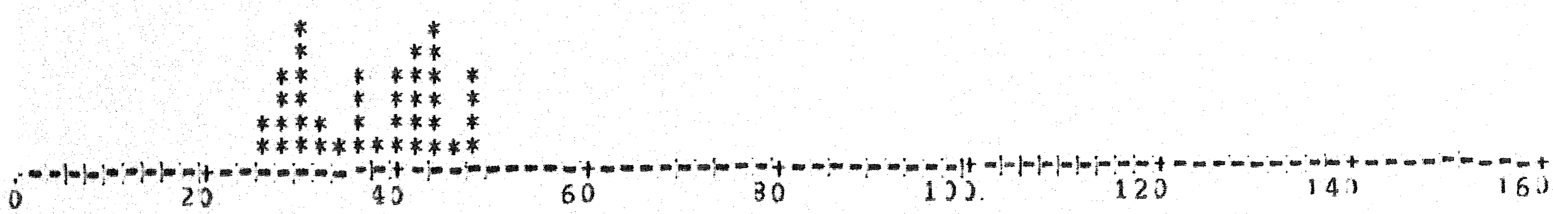


HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS   Continued.....

Class identification number 5   Band sequence number



Class identification number 5   Band sequence number   7



```
Band sequence number   4
 +---------+---------+---------+---------+---------+---------+---------+---------+
 I                  ***1***                                                      I
 I                                                  ******2******                I
 I                          **********3**********                                I
 I                                       ********4*********                      I
 I                     *******5********                                          I
 +---------+---------+---------+---------+---------+---------+---------+---------+
 00        20        40        60        80        100       120       140       160
```

```
Band sequence number   5
 +---------+---------+---------+---------+---------+---------+---------+---------+
 I              ***1***                                                          I
 I                                                 ******2******                 I
 I                             ******3*******                                    I
 I                                         *****4*****                           I
 I                      *****5******                                             I
 +---------+---------+---------+---------+---------+---------+---------+---------+
 00        20        40        60        80        100       120       140       160
```

```
Band sequence number   5'
 +---------+---------+---------+---------+---------+---------+---------+---------+
 I   ***1***                                                                     I
 I                                                           ******2******       I
 I                                     *****3******                              I
 I                                            ************4************          I
 I                  **************5**************                                I
 +---------+---------+---------+---------+---------+---------+---------+---------+
 00        20        40        60        80        100       120       140       160
```

```
Band sequence number   7
 +---------+---------+---------+---------+---------+---------+---------+---------+
 I     **1***                                                                    I
 I                                        **2**                                  I
 I                            ****3*****                                         I
 I                                   *************4*************                 I
 I            *****5******                                                       I
 +---------+---------+---------+---------+---------+---------+---------+---------+
 00        20        40        60        80        100       120       140       160
```

Confusion Matrix for training data set

	Class 1	Class 2	Class 3	Class 4	Class 5
Class 1	40	0	0	0	0
Class 2	0	40	0	0	0
Class 3	0	0	40	0	0
Class 4	0	0	0	40	0
Class 5	0	0	0	0	40

Confusion Matrix for training data set

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Class 1	40	0	0	0	0	0
Class 2	0	40	0	0	0	0
Class 3	0	0	40	0	0	0
Class 4	0	0	0	11	0	29
Class 5	0	0	0	0	40	0
Class 6	0	0	0	5	0	35

class 1 :water ;class 2 :barren land,loose sand ;class 3 :built-up area
class 4 :cultivated land ;class 5 :less depth water ;class 6:orchards

(Divergence/Transformed divergence)

Class Combinations

Band comb.	Avg. Div.	1 2	1 3	1 4	1 5	2 3	2 4	2 5	3 4	3 5	4 5
4	69.87 1681.75	340 2000	40 1986	57 1998	129 1999	15 1724	3 1329	18 1808	71 1999	1 403	14 1665
5	120.84 1897.62	515 2000	98 1999	75 1999	252 2000	18 1794	15 1755	24 1906	141 1999	11 1522	53 1997
6	253.34 1880.28	1137 2000	356 2000	88 1999	581 2000	10 1442	15 1753	116 1999	189 2000	17 1762	20 1838
7	237.51 1957.59	998 2000	323 2000	50 1995	543 2000	17 1774	20 1845	46 1993	300 2000	38 1983	37 1981
4 5	145.07 1955.07	569 2000	101 1999	91 1999	271 2000	26 1927	19 1335	40 1986	231 2000	18 1801	80 1999
4 6	262.97 1931.73	1181 2000	358 2000	104 1999	585 2000	20 1852	19 1325	117 1999	202 2000	17 1767	21 1870
4 7	285.90 1993.84	1178 2000	351 2000	116 1999	578 2000	33 1970	35 1974	59 1998	391 2000	47 1994	65 1999
5 6	301.57 1979.54	1239 2000	363 2000	128 1999	618 2000	24 1910	25 1920	139 1999	350 2000	37 1964	93 1999
5 7	276.05 1994.86	1095 2000	351 2000	111 1999	594 2000	39 1985	35 1975	50 1996	373 2000	44 1991	65 1999
6 7	362.37 1994.65	1537 2000	462 2000	107 1999	797 2000	35 1975	34 1973	140 1999	404 2000	52 1997	82 1999
4 5 6	309.41 1990.08	1259 2000	372 2000	130 1999	624 2000	34 1973	29 1947	144 1999	367 2000	35 1974	96 1999
4 5 7	312.36 1993.09	1193 2000	368 2000	132 1999	643 2000	47 1994	42 1989	70 1999	474 2000	51 1995	99 1999
4 6 7	375.04 1998.25	1539 2000	472 2000	135 1999	802 2000	47 1994	42 1990	141 1999	434 2000	55 1997	89 1999
5 6 7	392.71 1998.59	1539 2000	488 2000	145 1999	819 2000	53 1997	41 1989	152 1999	511 2000	60 1994	114 1999
4 5 6 7	402.28 1999.40	1553 2000	490 2000	150 1999	838 2000	73 1999	48 1995	156 2000	531 2000	61 1994	118 1999

(Divergence/Transformed divegence)

Class Combinations

Comb. Avg. Div.	1/2	1/3	1/4	1/5	1/6	2/3	2/4	2/5
57.68/1555.70	342/2000	40/1986	57/1998	129/1999	15/1724	3/1329	18/1808	71/1999
101.16/1755.71	515/2000	98/1999	75/1999	252/2000	18/1794	15/1755	24/1906	141/1999
214.94/1720.89	1137/2000	356/2000	88/1999	581/2000	10/1442	16/1758	116/1999	189/2000
199.82/1753.55	998/2000	323/2000	50/1996	543/2000	17/1774	20/1345	46/1993	300/2000
121.21/1817.58	569/2000	101/1999	91/1999	271/2000	26/1927	19/1335	40/1986	231/2000
223.18/1807.13	1181/2000	358/2000	104/1999	586/2000	20/1852	19/1325	117/1999	202/2000
237.01/1894.10	1178/2000	351/2000	116/1999	578/2000	33/1970	35/1974	59/1998	391/2000
253.41/1841.58	1239/2000	363/2000	128/1999	618/2000	24/1910	25/1920	139/1999	350/2000
228.37/1888.88	1095/2000	351/2000	111/1999	594/2000	39/1985	35/1975	50/1996	373/2000
301.15/1886.55	1507/2000	462/2000	107/1999	797/2000	35/1975	34/1973	140/1999	404/2000
261.12/1873.96	1259/2000	372/2000	130/1999	624/2000	34/1973	29/1947	144/1999	367/2000
258.16/1915.99	1193/2000	368/2000	132/1999	643/2000	47/1994	42/1989	70/1999	474/2000
312.79/1927.30	1539/2000	472/2000	135/1999	802/2000	47/1994	42/1990	141/1999	434/2000
325.30/1923.08	1539/2000	488/2000	145/1999	819/2000	53/1997	41/1989	152/1999	511/2000

2	3	3	3	4	4	5
6	4	5	6	5	6	6
1	14	128	15	8	0	13
304	1665	1999	1724	1309	0	1648
11	53	236	14	14	0	43
1522	1997	2000	1653	1670	44	1991
17	20	531	5	21	0	31
1762	1838	2000	1150	1858	42	1959
38	37	534	2	15	2	67
1983	1981	2000	484	1698	544	1999
18	80	254	22	17	0	71
1801	1999	2000	1883	1785	44	1999
17	21	542	19	22	0	33
1767	1870	2000	1814	1880	123	1971
47	66	557	19	25	3	89
1994	1999	2000	1822	1918	732	1999
32	93	546	17	26	0	95
1964	1999	2000	1777	1923	126	1999
44	63	539	16	25	3	79
1991	1999	2000	1754	1920	709	1999
52	82	760	8	26	5	91
1997	1999	2000	1318	1926	1105	1999
36	96	559	34	28	1	98
1979	1999	2000	1972	1946	290	1999
51	99	575	28	30	4	110
1996	1999	2000	1945	1953	874	1999
55	89	773	21	30	6	99
1997	1999	2000	1859	1956	1118	1999

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```
*****************************************************************************
        This program STATAN is to perform statistical analysis           *
  of the training data set and plots HISTOGRAMS (cf STAT04) and          *
  COSPECTRAL PLOT (cf STAT05) for different classes. It also             *
  calculates DIVERGENCE and TRANSFORMED DIVERGENCE to show the           *
  sepratibility of different classes.                                    *
*****************************************************************************
                            Main Program                                  *
      PROGRAM STATAN
      DIMENSION ICOMBO(15,6)
      COMMON /AREA1/TDMEAN,TDCVAR,TDDET,TD
      DATA IR,IW/23,24/
      ICLASS=5 ; IDATA=40
      CALL STAT01(ICLASS,IDATA)
      CALL STAT03(ICLASS,IDATA)
      CALL STAT07(ICLASS,2,NCOMB,ICOMBO)
      TYPE *,NCOMB
      WRITE(IW,200)
      DO 101 I=1,2
      WRITE(IW,201) (ICOMBO(K,I),K=1,NCOMB)
01    CONTINUE
      DO 100 IBAND=1,4
      CALL STAT07(4,IBAND,NCOMB,ICOMBO)
      DO 100 I=1,NCOMB
      CALL STAT06(ICLASS,IBAND,ICOMBO,I)
00    CONTINUE
00    FORMAT('1',5(/),10X,34('-'),'DIVERGENCE TABLE',34('-'))//
     110X,25X,'(Divergence/Transformed divegence)'//
     110X,'Band comb.  Avg. Div.    ',20X,'Class Combinations'/)
01    FORMAT(/32X,15I6/)
      STOP
      END

      SUBROUTINE STAT01(ICLASS,IDATA)
*****************************************************************************
      This subroutine is to perform statistical analysis of training
      data.
*****************************************************************************
      REAL TDCVAR(6,4,4),TDMEAN(6,4),A(4,4),TDDET(6)
      REAL AD1(4,4),B(4,4),Z(4),TDCINV(6,4,4),CORCOF(4,4)
      INTEGER TD(6,40,4),MINMAX(6,4,2)
      COMMON /AREA1/ TDMEAN,TDCINV,TDCVAR,TDDET,TD
      DATA IR,IW/07,24/
      CALL X04AAF(1,5)
      OPEN(UNIT=IR,DEVICE='DSKC',FILE='TRDATA')
      OPEN(UNIT=IW,DEVICE='DSKC')
      DO 104 I=1,ICLASS
      DO 104 K=1,4
      READ(IR,*) ((TD(I,J,K),K=1,4),J=1,IDATA)
      READ(IR,*) ((TD(I,J,K),J=1,IDATA),K=1,4)
```

A P P E N D I X

STATANFOR


```
 3    CONTINUE
      WRITE(IW,200) (((TD(I,J,K),K=1,4),J=1,IDATA),I=1,ICLASS)
      DO 105 I=1,ICLASS
      DO 105 J=1,4
      TDMEAN(I,J)=0.0
```

Calculation of reflectance value mean for different classes in different bands.

```
      DO 105 K=1,IDATA
      TDMEAN(I,J)=TDMEAN(I,J)+((TD(I,K,J))/FLOAT(IDATA))
105   CONTINUE
      WRITE(IW,201) ((TDMEAN(I,J),J=1,4),I=1,ICLASS)
      DO 106 I=1,ICLASS
      DO 106 J=1,4
      MIN=TD(I,1,J) ; MAX=MIN
      DO 107 K=1,40
      IF(TD(I,K,J)>=MIN) GOTO 108
      MIN=TD(I,K,J)
108   IF(TD(I,K,J)<=MAX) GOTO 107
      MAX=TD(I,K,J)
107   CONTINUE
      MINMAX(I,J,1)=MIN ; MINMAX(I,J,2)=MAX
106   CONTINUE
```

Generation of Variance Covariance matrix TDCVAR

```
      DO 100 I=1,ICLASS
      DO 100 J=1,4
      DO 100 K=1,J
      TDCVAR(I,J,K)=0.0
      DO 100 L=1,IDATA
      TDCVAR(I,J,K)=TDCVAR(I,J,K)+((TD(I,L,K)-TDMEAN(I,K))*(TD(I,L,J)-
     1TDMEAN(I,J))/(FLOAT(IDATA-1)))
100   CONTINUE
      DO 101 I=1,ICLASS
      DO 101 J=1,3
      DO 101 K=J+1,4
      TDCVAR(I,J,K)=TDCVAR(I,K,J)
101   CONTINUE
```

Calculation of Coefficient of corelation matrix

```
      DO 103 I=1,ICLASS
      DO 103 J=1,4
      DO 103 K=1,4
      CORCOF(J,K)=(TDCVAR(I,J,K)/SQRT(TDCVAR(I,J,J)*TDCVAR(I,K,K)))
      A(J,K)=TDCVAR(I,J,K)
      A01(J,K)=A(J,K)
```

A P P E N D I X


```
      WRITE(IW,202) I,((A(J,K),K=1,4),J=1,4)
C     Computation of Inverse Variance covariance matrix TDCINV (B)
      CALL F01AAF(AD1,4,4,B,4,Z,IFAIL)
C     Computation of Determinant of Variance Covariance matrix
      CALL F03AAF(A,4,4,ADET,Z,IFAIL)
      TDDET(I)=ADET
      WRITE(IW,203) I,((B(J,K),K=1,4),J=1,4)
      WRITE(IW,204) I
      WRITE(IW,205) (IB,IB=4,7)
      WRITE(IW,206) (TDMEAN(I,J),J=1,4),(TDCVAR(I,J,J),J=1,4)
      WRITE(IW,207) ((MINMAX(I,J,K),J=1,4),K=1,2)
      WRITE(IW,208)
      DO 109 K=4,7
09    WRITE(IW,209) (K,(TDCVAR(I,J,K-3),J=1,K-3))
      WRITE(IW,210)
      DO 110 K=4,7
10    WRITE(IW,209) (K,(B(J,K-3),J=1,K-3))
      WRITE(IW,211)
      DO 111 K=4,7
11    WRITE(IW,209) (K,(CORCOF(J,K-3),J=1,K-3))
      WRITE(IW,212)
      DO 102 J=1,4
      DO 102 K=1,4
      TDCINV(I,J,K)=B(J,K)
2     CONTINUE
      CALL STAT04(TD,ICLASS,IDATA)
      CALL STAT05(MINMAX,ICLASS)
C     Format comands used for subroutine
0     FORMAT(' TRAINING DATA SET'//(10(6X,4(4I4,4X)/)//))
1     FORMAT(' MEAN OF REFLECTANCES IN EACH BAND'//5(2X,4F11.3,/))
2     FORMAT(//' VARIANCE COVARAINCE MATRIX IN CLASS 'I2//,(4F11.3))
3     FORMAT(//' INVERSE VAR COVAR MATRIX IN CLASS 'I4//,(4F11.3))
4     FORMAT('1',I5(/),10X,'Statistics for class ',I6/)
5     FORMAT(10X,60('-')/10X,' Band :',4I12/10X,60('-'))
6     FORMAT(/10X,' Mean',5X,4F12.2/10X,' Variance ',4F12.2)
7     FORMAT(10X,' Minimum',9X,I3,3I12/10X,' Maximum',9X,I3,3I12//)
8     FORMAT(25X,'Variance Covariance matrix'/)
9     FORMAT(10X,' Band',I2,3X,4F12.2)
0     FORMAT(//25X,'Inverse Variance Covariance matrix',/)
1     FORMAT(//25X,'Correlation coefficients ',/)
2     format(/10x,60('-'))
      RETURN
      END
```

A P P E N D I X


```
      ******************************************************************
      SUBROUTINE STAT02(A,RD,PRO)
      ******************************************************************
      DIMENSION A(4,4),RD(4),TEMP(4)
      PRO=0.0
      DO 100 I=1,4
      TEMP(I)=0.0
      CONTINUE
      DO 101 I=1,4
      DO 101 J=1,4
      TEMP(I)=TEMP(I)+(A(I,J)*RD(J))
)1    CONTINUE
      DO 102 I=1,4
      PRO =PRO+TEMP(I)*RD(I)
)2    CONTINUE
      RETURN
      END

      SUBROUTINE STAT03(ICLASS,IDATA)
      ******************************************************************
      Subroutine to prepare the Confusion Matrix
      ******************************************************************
      REAL RDEV(6,4),RD(4),A(4,4),PROB(6),TDMEAN(6,4),TDCINV(6,4,4)
      REAL TDDET(6),TDCVAR(6,4,4)
      INTEGER DECCLS(6,40),CONMAT(6,6),TD(6,40,4)
      COMMON /AREA1/ TDMEAN,TDCINV,TDCVAR,TDDET,TD
      DATA TW/24/
      DO 100 I=1,ICLASS
      DO 100 J=1,ICLASS
0     CONMAT(I,J)=0
      DO 101 IC=1,ICLASS
      DO 101 ID=1,IDATA
      DO 103 I=1,ICLASS
      DO 104 J=1,4
      RD(J)=FLOAT(TD(IC,ID,J))-TDMEAN(I,J)
      DO 104 K=1,4
      A(J,K)=TDCINV(I,J,K)
4     CONTINUE
      CALL STAT02(A,RD,PRO)
      TYPE *,RD,PRO
      PROB(I)=(-0.5*(ALOG(TDDET(I))+PRO))
3     CONTINUE
      PMAX=-10000.0 ; DECCLS(IC,ID)=0
      PAUSE 107
      DO 105 I=1,ICLASS
      IF(PROB(I)<=PMAX) GOTO 105
      PMAX=PROB(I)
      DECCLS(IC,ID)=I
      TYPE *,PROB,I
5     CONTINUE
```

APPENDIX

STATANFOR


```
      IDECLS=DECCLS(IC,ID)
      IF(IC.EQ.IDECLS) GOTO 102
      TYPE *,IC,IDECLS,ID
02    CONTINUE
      CONMAT(IC,IDECLS)=CONMAT(IC,IDECLS)+1
01    CONTINUE
      IF (ICLASS.EQ.6) GOTO 107
      WRITE(IW,201) (I,I=1,ICLASS)
      GOTO 108
07    WRITE(IW,202) (I,I=1,ICLASS)
08    CONTINUE
01    FORMAT('1',15(/),10X,'Confusion Matrix for training data set'//,
     124X,5('Class'I2,4X))
02    FORMAT('1',15(/),10X,'Confusion Matrix for training data set'//,
     124X,6('Class'I2,4X))
      DO 106 I=1,ICLASS
      WRITE(IW,200) I,(CONMAT(I,J),J=1,ICLASS)
00    FORMAT(/10X,'Class'I2,6I11)
06    CONTINUE
      RETURN
      END

      SUBROUTINE STAT04(TD,ICLASS,IDATA)
C***********************************************************************
C     Subroutine to prepare the Histogram for different classes
C***********************************************************************
      INTEGER TD(6,40,4),HIST(6,4,80)
      REAL HISTGM(20,80)
      DATA IR,IW/23,24/
      WRITE(IW,203)
      ICIB=0
      DO 100 IC=1,ICLASS
      DO 100 IB=1,4
      ICIB=ICIB+1
      IF(ICIB.NE.1.AND.MOD(ICIB,2).EQ.1) WRITE (IW,204)
      DO 104 I=1,80
4     HIST(IC,IB,I)=0
      DO 102 ID=1,IDATA
      ICOMP=TD(IC,ID,IB)/2
      HIST(IC,IB,ICOMP)=HIST(IC,IB,ICOMP)+1
2     CONTINUE
      DO 101 I=1,20
      DO 101 J=1,80
      HISTGM(I,J)=' '
1     CONTINUE
      DO 103 I=1,80
      IF(HIST(IC,IB,I).EQ.0) GOTO 103
      DO 103 II=1,HIST(IC,IB,I)
      HISTGM(II,I)='*'
3     CONTINUE
```

A P P E N D I X


```
      IBAND=IB+3
      WRITE(IW,202) IC,IBAND
      WRITE(IW,200) ((HISTGM(I,J),J=1,80),I=20,1,-1)
      WRITE(IW,201)
 00   CONTINUE
 0    FORMAT(15X,80A1)
 01   FORMAT(14X,'+',8(9('-'),'+')/14X,'0',8X,'20',8X,'40',8X,'60',
      18X,'80',7X,'100',7X,'120',7X,'140',7X,'160'///)
 02   FORMAT(10X,'Class identification number 'I2
      1,10X,'Band sequence number          'I2)
 03   FORMAT('1'20(/)9X'HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS'//)
 04   FORMAT('1',20(/),9X,'HISTOGRAMS FOR DIFFERENT CLASSES IN 4 BANDS'
      1,'    Continued....'//)
      RETURN
      END

      SUBROUTINE STAT05(MINMAX,ICLASS)
*****************************************************************
      Subroutine to prepare the Cospectral Plot of training data set
*****************************************************************
      INTEGER MINMAX(6,4,2)
      REAL IND(6),COSPTL(79)
      DATA IW,IND/24,'1','2','3','4','5','6'/
      WRITE(IW,203)
      DO 100 IB=1,4
      IBAND=IB+3
      WRITE(IW,200) IBAND
      DO 101 IC=1,ICLASS
      MIN=MINMAX(IC,IB,1)/2
      MAX=MINMAX(IC,IB,2)/2
      DO 102 I=1,79
 02   COSPTL(I)=' '
      MID=MIN+((MAX-MIN)/2)
      DO 103 I=MIN,MAX
      IF(I.EQ.MID) GOTO 104
      COSPTL(I)='*'
      GOTO 103
 04   CONTINUE
      COSPTL(I)=IND(IC)
 03   CONTINUE
      WRITE(IW,201) COSPTL
 01   CONTINUE
      WRITE(IW,202)
 00   CONTINUE
 00   FORMAT(10X,'Band sequence number ',I2//14X,'+',8(9('-'),'+'))
 01   FORMAT(14X,'I',79A1,'I')
 02   FORMAT(14X,'+',8(9('-'),'+')/14X,'00',7X,'20',8X,'40',8X,'60',
      18X,'80',7X,'100',7X,'120',7X,'140',7X,'160'///)
 03   FORMAT('1',5(/),9X,'COSPECTRAL PLOTS '/)
      RETURN
```

```
      END
      SUBROUTINE STAT06(ICLASS,IBAND,ICOMBO,NCOMB)
*****************************************************************************
      Subroutine for calculation of DIVERGENCE and TRANSFORMED DIVERG>
*****************************************************************************
      INTEGER ICOMBO(15,6),ITDIV(6,6),IDIV(6,6),ICMB(15,6)
      REAL TDMEAN(6,4),TDCVAR(6,4,4),CVAR(6,4,4),WKSP(4),A(4,4)
      REAL DIV(6,6),TDIV(6,6),VACB(4,4),VBCB(4,4),VCCB(4,4),MACD(4)
      REAL TDCINV(6,4,4),CVINV(6,4,4),B(4,4)
      COMMON /AREA1/ TDMEAN,TDCINV,TDCVAR
      DATA IW/24/
      ADIV1=0.0 ; ADIV2=0.0
      DO 109 I=1,ICLASS
      DO 109 J=1,4
      DO 109 K=1,4
      CVAR(I,J,K)=0.0
      CVINV(I,J,K)=0.0
09    CONTINUE
      DO 107 I=1,ICLASS
      DO 106 II=1,IBAND
      I1=ICOMBO(NCOMB,II)
      DO 106 JJ=1,IBAND
      J1=ICOMBO(NCOMB,JJ)
      A(II,JJ)=TDCVAR(I,I1,J1)
      CVAR(I,II,JJ)=A(II,JJ)
06    CONTINUE
      CALL F01AAF(A,4,IBAND,B,4,WKSP,IFAIL)
      DO 108 II=1,4
      DO 108 JJ=1,4
      CVINV(I,II,JJ)=B(II,JJ)
08    CONTINUE
07    CONTINUE
      DO 100 I=1,ICLASS
      DIV(I,I)=0.0
      TDIV(I,I)=0.0
00    CONTINUE
      ISUM=0
      WRITE(IW,200) (I,I=1,ICLASS)
      DO 101 I=2,ICLASS
      DO 101 J=1,I-1
      DO 102 II=1,IBAND
      DO 103 JJ=1,IBAND
      VACB(II,JJ)=CVAR(I,II,JJ)-CVAR(J,II,JJ)
      VBCB(II,JJ)=CVINV(J,II,JJ)-CVINV(I,II,JJ)
      VCCB(II,JJ)=CVINV(I,II,JJ)+CVINV(J,II,JJ)
03    CONTINUE
      I1=ICOMBO(NCOMB,II)
      MACD(II)=TDMEAN(I,I1)-TDMEAN(J,I1)
02    CONTINUE
```

```
      TR1=0.0 ; TR2=0.0
      DO 104 II=1,IBAND
      DO 104 JJ=1,IBAND
      TR1=TR1+VACB(II,JJ)*VBCB(JJ,II)
      TR2=TR2+MACD(II)*VCCB(II,JJ)*MACD(JJ)
04    CONTINUE
      DIV(I,J)=0.5*(TR1+TR2)
      IDIV(I,J)=IFIX(DIV(I,J))
      IF(DIV(I,J) > 350.) DIV(I,J)=350.0
      TDIV(I,J)=2000.0*(1-EXP(-DIV(I,J)/8.0))
      ITDIV(I,J)=IFIX(TDIV(I,J))
      ADIV1=ADIV1+TDIV(I,J)
      ADIV2=ADIV2+DIV(I,J)
      ISUM=ISUM+1
01    CONTINUE
      ATDIV1=ADIV1/ISUM
      ATDIV2=ADIV2/ISUM
      DO 105 I=1,ICLASS
      WRITE(IW,201) (I,(DIV(I,J),J=1,I))
      WRITE(IW,202) (TDIV(I,J),J=1,I)
05    CONTINUE
      DO 110 I=1,IBAND
      ICMB(NCOMB,I)=ICOMBO(NCOMB,I)+3
10    CONTINUE
      WRITE(IW,203) (ICMB(NCOMB,I),I=1,IBAND)
      WRITE(IW,204) ATDIV2,((TDIV(I,J),J=1,I-1),I=2,ICLASS)
      WRITE(IW,205) ATDIV1,((ITDIV(I,J),J=1,I-1),I=2,ICLASS)
00    FORMAT(15(/),10X,'DIVERGENCE/TRANSFORMED DIVERGENCE'//,
     124X,5('Class',I2,4X))
01    FORMAT(/10X,'Class',I2,3X,5F11.2)
02    FORMAT(20X,5F11.2)
03    FORMAT(10X,4I2)
04    FORMAT(19X,F11.2,3X,15I6)
05    FORMAT(19X,F11.2,3X,15I6//)
      RETURN
      END

      SUBROUTINE STAT07(NC,NPC,NCOMB,ICOMBO)
      ***********************************************************
      Subroutine to find out all the combinations of Bands and/or
      Classes .
      ***********************************************************
      DIMENSION ICOMBO(15,6)
      NCOMB=0
      IE1=NC-NPC+1
      DO 201 I=1,IE1
      IF(NPC.EQ.1) GOTO 107
      IB2=I+1
      IE2=NC-NPC+2
      DO 202 II=IB2,IE2
```

A P P E N D I X


```
      IF(NPC.EQ.2) GOTO 107
      IB3=II+1
      IE3=NC-NPC+3
      DO 203 III=IB3,IE3
      IF(NPC.EQ.3) GOTO 107
      IB4=III+1
      IE4=NC-NPC+4
      DO 204 IIII=IB4,IE4
      IF(NPC.EQ.4) GOTO 107
      IB5=IIII+1
      IE5=NC-NPC+5
      DO 205 IIIII=IB5,IE5
      IF(NPC.EQ.5) GOTO 107
      IB6=IIIII+1
      IE6=NC-NPC+6
      DO 206 IIIIII=IB6,IE6
7     NCOMB=NCOMB+1
      GOTO (101,102,103,104,105,106),NPC
6     ICOMBO(NCOMB,6)=IIIIII
5     ICOMBO(NCOMB,5)=IIIII
4     ICOMBO(NCOMB,4)=IIII
3     ICOMBO(NCOMB,3)=III
2     ICOMBO(NCOMB,2)=II
1     ICOMBO(NCOMB,1)=I
6     CONTINUE
5     CONTINUE
4     CONTINUE
3     CONTINUE
2     CONTINUE
1     CONTINUE
      RETURN
      END
```

APPENDIX


```
**************************************************************************
          This program BCLASS FOR is generated to classify the       *
     pixels based upon their reflectance values using MAXIMUM LIKE   *
     LYHOOD / BAYES' CLASSIFIER (cf bclass) . It also gives as an    *
     output the line printer map of the defined area , the extent    *
     of which has been defined as 240 PIXELS X 234 LINES .This       *
     program retrieves the ref values in all the four bands using    *
     subroutine BCLS04. The line printer map is output to data file  *
     HRDCPn DAT , where n can be any number varying from 1 to 5 .    *
**************************************************************************
      PROGRAM MAIN
      INTEGER HEADPX(4,600),SAPROB(5),APPRB(5)
      DATA IR,IW/23,24/
      OPEN(UNIT=IR,DEVICE='DSKC')
      OPEN(UNIT=IW,DEVICE='DSKC')
      OPEN(UNIT=08,DEVICE='DSKC',FILE='HRDCP1')
      OPEN(UNIT=09,DEVICE='DSKC',FILE='HRDCP2')
      OPEN(UNIT=10,DEVICE='DSKC',FILE='HRDCP3')
      OPEN(UNIT=11,DEVICE='DSKC',FILE='HRDCP4')
      OPEN(UNIT=12,DEVICE='DSKC',FILE='HRDCP5')
      ILENTH=120 ; ILINE=78 ; ICLASS=5 ; IDATA=40
      CALL BCLS01(ICLASS,IDATA)
      TYPE 200
      ACCEPT *, NBC,NBR
      TYPE 204
      ACCEPT *, ILENTH,ILINE
      IBC=NBC
      DO 101 I=1,ILENTH
      HEADPX(1,I)=IBC/1000
      HEADPX(2,I)=(IBC-HEADPX(1,I)*1000)/100
      HEADPX(3,I)=(IBC-HEADPX(1,I)*1000-HEADPX(2,I)*100)/10
      HEADPX(4,I)=IBC-HEADPX(1,I)*1000-HEADPX(2,I)*100-HEADPX(3,I)*10
      IBC=IBC+1
01    CONTINUE
      DO 105 IKL=1,3
      PAUSE 000
      IFINL=0 ; IW1=8
)2    CONTINUE
      INITL=IFINL+1 ; IFINL=INITL+119
      WRITE(IW1,203)
      WRITE(IW1,201) ((HEADPX(I,J),J=INITL,IFINL),I=1,4)
      WRITE(IW1,202)
      IW1=IW1+1
      IF(IFINL < ILENTH) GOTO 102
      DO 100 I=1,ILINE
      IBR=NBR+I-1
      TYPE *, IKL,I
      CALL BCLS04(ILENTH,NBC,IBR)
      PAUSE 230
      CALL BCLS02(IBR,ILENTH,ICLASS,IDATA,APPRB)
```

```
        DO 104 II=1,ICLASS
        SAPROB(II)=SAPROB(II)+APPRB(II)
04      CONTINUE
00      CONTINUE
        IFINL=0 ; IW1=8
03      CONTINUE
        INITL=IFINL+1 ; IFINL=INITL+119
        WRITE(IW1,202)
        WRITE(IW1,201) ((HEADPX(I,J),J=INITL,IFINL),I=1,4)
        IW1=IW1+1
        IF(IFINL < ILENTH) GOTO 103
        NBR=NBR+ILINE
05      CONTINUE
        WRITE(IW,205) SAPROB
00      FORMAT('   TYPE IN THE FIRST PIXEL NUMBER AND SCAN LINE NUMBER')
01      FORMAT((6X,120I1))
02      FORMAT(' ')
03      FORMAT('1')
04      FORMAT('   TYPE IN TOTAL PIXELS AND LINES TO BE ANALYSISED')
05      FORMAT(//'    APRIORI PROBABILITY OF CLASSES'//,4X,6I15)
        STOP
        END

        SUBROUTINE BCLS01(ICLASS,IDATA)
        ***********************************************************************
        Subroutine for statistical analysis of training data set
        ***********************************************************************
        REAL TDCVAR(5,4,4),TDMEAN(5,4),A(4,4),TDDET(5)
        REAL AD1(4,4),B(4,4),Z(4)
        INTEGER TD(5,40,4),MINMAX(5,4,2)
        COMMON /AREA1/ TDMEAN,TDCVAR,TDDET,TD
        DATA IR,IW/07,24/
        CALL X04AAF(1,5)
        OPEN(UNIT=IR,DEVICE='DSKC',FILE='TRDATA')
        OPEN(UNIT=IW,DEVICE='DSKC')
        DO 104 I=1,ICLASS
        DO 104 K=1,4
        READ(IR,*) ((TD(I,J,K),K=1,4),J=1,IDATA)
        READ(IR,*) ((TD(I,J,K),J=1,IDATA),K=1,4)
04      CONTINUE
00      FORMAT(' TRAINING DATA SET'//(8(2X,5(4I4,5X)/)//))
        WRITE(IW,200) (((TD(I,J,K),K=1,4),J=1,IDATA),I=1,ICLASS)
        DO 105 I=1,ICLASS
        DO 105 J=1,4
        TDMEAN(I,J)=0.0
        DO 105 K=1,IDATA
        TDMEAN(I,J)=TDMEAN(I,J)+((TD(I,K,J))/FLOAT(IDATA))
05      CONTINUE
        WRITE(IW,201) ((TDMEAN(I,J),J=1,4),I=1,ICLASS)
01      FORMAT(' MEAN OF REFLECTANCES IN EACH BAND'//5(2X,4F11.3,/))
```

A P P E N D I X


```
      DO 106 I=1,ICLASS
      DO 106 J=1,4
      MIN=TD(I,1,J) ; MAX=MIN
      DO 107 K=1,40
      IF(TD(I,K,J)>=MIN) GOTO 108
      MIN=TD(I,K,J)
8     IF(TD(I,K,J)<=MAX) GOTO 107
      MAX=TD(I,K,J)
7     CONTINUE
      MINMAX(I,J,1)=MIN ; MINMAX(I,J,2)=MAX
5     CONTINUE
      DO 100 I=1,ICLASS
      DO 100 J=1,4
      DO 100 K=1,J
      TDCVAR(I,J,K)=0.0
      DO 100 L=1,IDATA
      TDCVAR(I,J,K)=TDCVAR(I,J,K)+((TD(I,L,K)-TDMEAN(I,K))*(TD(I,L,J)-
     1TDMEAN(I,J))/(FLOAT(IDATA-1)))
)     CONTINUE
      DO 101 I=1,ICLASS
      DO 101 J=1,3
      DO 101 K=J+1,4
      TDCVAR(I,J,K)=TDCVAR(I,K,J)
1     CONTINUE
      DO 102 I=1,ICLASS
      DO 103 J=1,4
      DO 103 K=1,4
      A(J,K)=TDCVAR(I,J,K)
      AD1(J,K)=A(J,K)
3     CONTINUE
      WRITE(IW,202) I,((A(J,K),K=1,4),J=1,4)
2     FORMAT(//' VARIANCE COVARAINCE MATRIX IN CLASS 'I2//,(4F11.3))
      CALL F01AAF(AD1,4,4,B,4,Z,IFAIL)
      CALL F03AAF(A,4,4,ADET,Z,IFAIL)
      TDDET(I)=ADET
      WRITE(IW,203) I,((B(J,K),K=1,4),J=1,4)
3     FORMAT(//' INVERSE VAR COVAR MATRIX IN CLASS 'I4//,(4F11.3))
      DO 102 J=1,4
      DO 102 K=1,4
      TDCVAR(I,J,K)=B(J,K)
?     CONTINUE
      CALL BCLS05(TD,ICLASS,IDATA)
      CALL BCLS06(MINMAX,ICLASS)
      RETURN
      END

      SUBROUTINE BCLS02(NBR,ILENTH,ICLASS,IDATA,APROB)
******************************************************************
      Subroutine for classify the pixels using maximum likelyhood
      method
```

```
*************************************************************************
REAL RDEV(5,4),RD(4),A(4,4),MAPLPT(5,600),PROB(5)
REAL TDMEAN(5,4),TDCVAR(5,4,4),TDDET(5)
INTEGER R(4,600),DECCLS(600),TD(5,40,4),APROB(5)
COMMON /AREA1/ TDMEAN,TDCVAR,TDDET,TD
COMMON /AREA2/ R
DATA IR,IW/23,24/
OPEN(UNIT=IR,DEVICE='DSK',FILE='INPUT')
OPEN(UNIT=IR,DEVICE='DSKC')
OPEN(UNIT=IW,DEVICE='DSKC')
READ(IR,*) ((R(I,J),J=1,120),I=1,4)
DO 114 I=1,ICLASS
4  APROB(I)=0.0
DO 104 IP=1,ILENTH
DO 100 I=1,ICLASS
DO 100 J=1,4
RDEV(I,J)=R(J,IP)-TDMEAN(I,J)
0  CONTINUE
PMAX=-10000.0; DECCLS(IP)=0
DO 101 I=1,ICLASS
DO 102 J=1,4
RD(J)=RDEV(I,J)
DO 102 K=1,4
A(J,K)=TDCVAR(I,J,K)
2  CONTINUE
CALL BCLS03(A,RD,PRO)
PROB(I)= -0.5*(ALOG(TDDET(I))+PRO)
1  CONTINUE
TYPE *, SPROB,IP
DO 103 J=1,ICLASS
PROB(J)=PROB(J)/SPROB
IF(PROB(J)<=PMAX) GOTO 103
PMAX=PROB(J)
DECCLS(IP)=J
3  CONTINUE
APROB(DECCLS(IP))=APROB(DECCLS(IP))+1
GOTO (105,106,107,108,109) DECCLS(IP)

Assigning characters to class identification mark

5  CONTINUE
MAPLPT(1,IP)=' ' ; MAPLPT(2,IP)=' '
MAPLPT(3,IP)=' ' ; MAPLPT(4,IP)=' '
MAPLPT(5,IP)=' '
GOTO 104
6  CONTINUE
MAPLPT(1,IP)='M' ; MAPLPT(2,IP)='W'
MAPLPT(3,IP)=' ' ; MAPLPT(4,IP)=' '
MAPLPT(5,IP)='.'
GOTO 104
```

```
7       CONTINUE
        MAPLPT(1,IP)='H' ; MAPLPT(2,IP)='I'
        MAPLPT(3,IP)='X' ; MAPLPT(4,IP)='O'
        MAPLPT(5,IP)='*'
        GOTO 104
8       CONTINUE
        MAPLPT(1,IP)='/' ; MAPLPT(2,IP)=' '
        MAPLPT(3,IP)=' ' ; MAPLPT(4,IP)=' '
        MAPLPT(5,IP)=' '
        GOTO 104
9       CONTINUE
        MAPLPT(1,IP)='.' ; MAPLPT(2,IP)=' '
        MAPLPT(3,IP)=' ' ; MAPLPT(4,IP)=' '
        MAPLPT(5,IP)=' '
4       CONTINUE
        DO 113 I=1,ICLASS
        APROB(I)=APROB(I)/(FLOAT(ILENTH))
13      CONTINUE
        TYPE 999, (APROB(I),I=1,ICLASS)
9       FORMAT(6I15)
        IFINL=0 ; IW1=8
2       CONTINUE
        INITL=IFINL+1 ; IFINL=INITL+119
        WRITE(IW1,111) NBR,NBR
        WRITE(IW1,110)((MAPLPT(I,J),J=INITL,IFINL),I=1,5)
        IW1=IW1+1
        IF(IFINL < ILENTH) GOTO 112
0       FORMAT('+',5X,120A1)
1       FORMAT(I5,121X,I5)
        RETURN
        END

        ***********************************************************
        SUBROUTINE BCLS03(A,RD,PRO)
        ***********************************************************
        DIMENSION A(4,4),RD(4),TEMP(4)
        PRO=0.0
        DO 100 I=1,4
        TEMP(I)=0.0
0       CONTINUE
        DO 101 I=1,4
        DO 101 J=1,4
        TEMP(I)=TEMP(I)+(A(I,J)*RD(J))
1       CONTINUE
        DO 102 I=1,4
        PRO =PRO+TEMP(I)*RD(I)
2       CONTINUE
        RETURN
        END
```

```
      SUBROUTINE BCLS04(ILENTH,IPIX,LINE)
C***********************************************************************
C     Subroutine transfers a part of four consecutive records for
C     analysis to subroutine BCLASS . These four consecutive records
C     are for four bands and the part transfered is ILENTH pixels
C***********************************************************************
      INTEGER OCT(1124),BT1,BT2,BT3,BT4,BYTE(4500),ABC(4,600)
      INTEGER RECORD,BAND
      COMMON /AREA2/ ABC
      DATA IW/5/
      OPEN(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1124,
     1DENSITY='1600')
      DO 110 II=1,4
      READ(20)OCT
      J=1
      DO 116 I=1,1124
      BT1=OCT(I)/2^28
      BYTE(J)=BT1 ; J=J+1
      BT2=(OCT(I)-BT1*2^28)/2^20
      BYTE(J)=BT2; J=J+1
      BT3=(OCT(I)-BT1*2^28-BT2*2^20)/2^12
      BYTE(J)=BT3; J=J+1
      BT4=(OCT(I)-BT1*2^28-BT2*2^20-BT3*2^12)/2^4
      BYTE(J)=BT4; J=J+1
6     CONTINUE
      RECORD=BYTE(3)+BYTE(4)*256
      LINE=BYTE(7)+BYTE(8)*256
      BAND=7-(LINE*4-RECORD)
      WRITE(IW,111) LINE,IPIX
1     FORMAT(15X,'LINE NUBER= ',I4,'  PIXEL NUMBER =',I5)
      WRITE(IW,112)BAND,RECORD
2     FORMAT(15X,'BAND    =',I4,'     RECORD NUMBER = ',I5/)
      IZERO=1
      DO 125 I=9,400
5     IF (BYTE(I).EQ.0) IZERO=IZERO+1
      IPIXEL=IPIX+IZERO+8
      IPIXU=IPIXEL +(ILENTH-1)
      IPIXL=IPIXEL
      J=1
      DO 113 I=IPIXL,IPIXU
      IF(BYTE(I) < 0) BYTE(I)=BYTE(I)+256
      ABC(II,J)=BYTE(I)
      J=J+1
3     CONTINUE
0     CONTINUE
      CLOSE(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1124,
     1DENSITY='1600')
      RETURN
      END
```

A P P E N D I X


```
*     ****************************************************************
      SUBROUTINE BCLS05(TD,ICLASS,IDATA)
*     ****************************************************************
      INTEGER TD(5,40,4),HIST(5,4,80)
      REAL HISTGM(20,80)
      DATA IR,IW/23,24/
      DO 100 IC=1,ICLASS
      DO 100 IB=1,4
      DO 104 I=1,80
104   HIST(IC,IB,I)=0
      DO 102 ID=1,IDATA
      ICOMP=TD(IC,ID,IB)/2
      HIST(IC,IB,ICOMP)=HIST(IC,IB,ICOMP)+1
102   CONTINUE
      DO 101 I=1,20
      DO 101 J=1,80
      HISTGM(I,J)=' '
101   CONTINUE
      DO 103 I=1,80
      IF(HIST(IC,IB,I).EQ.0) GOTO 103
      DO 103 II=1,HIST(IC,IB,I)
      HISTGM(II,I)='*'
103   CONTINUE
      IBAND=IB+3
      WRITE(IW,202) IC,IBAND
*     WRITE(IW,200) ((I,(HISTGM(I,J),J=1,80)),I=20,1,-1)
      WRITE(IW,203) ((HISTGM(I,J),J=1,80),I=20,1,-1)
      WRITE(IW,201)
100   CONTINUE
200   FORMAT(12X,I2,'+',80A1)
201   FORMAT(14X,'+',16(4('-'),'+')/14X,'0',8X,'20',8X,'40',8X,'60',
     18X,'80',7X,'100',7X,'120',7X,'140',7X,'160'//)
202   FORMAT(10X,'Class identification number 'I2
     1,10X,'Band sequence number           'I2)
203   FORMAT(15X,80A1)
      RETURN
      END
*     ****************************************************************
      SUBROUTINE BCLS06(MINMAX,ICLASS)
*     ****************************************************************
      INTEGER MINMAX(5,4,2)
      REAL IND(5),COSPIL(79)
      DATA IW,IND/24,'1','2','3','4','5'/
      DO 100 IB=1,4
      IBAND=IB+3
      WRITE(IW,200) IBAND
      DO 101 IC=1,ICLASS
      MIN=MINMAX(IC,IB,1)/2
      MAX=MINMAX(IC,IB,2)/2
```

```
        DO 102 I=1,79
102     COSPTL(I)=' '
        MID=MIN+((MAX-MIN)/2)
        DO 103 I=MIN,MAX
        IF(I.EQ.MID) GOTO 104
        COSPTL(I)='*'
        GOTO 103
104     CONTINUE
        COSPTL(I)=IND(IC)
103     CONTINUE
        WRITE(IW,201) COSPTL
101     CONTINUE
        WRITE(IW,202)
100     CONTINUE
200     FORMAT(10X,'Band sequence number ',I2//14X,'+',16(4('-'),'+'))
201     FORMAT(14X,'I',79A1,'I')
202     FORMAT(14X,'+',16(4('-'),'+')/14X,'00',7X,'20',8X,'40',8X,'60',
       18X,'80',7X,'100',7X,'120',7X,'140',7X,'160'///)
        RETURN
        END
```

```
***********************************************************************
*       An interactive program to map a specified area on line printer
*       with 80 lines and 120 characters . It has ffecilities for
*       choice of maximum ten classes
***********************************************************************
*
*                      MAIN PROGRAM STARTS
        INTEGER IPIX(600),INTMAP(600,4),GRAY(15),HEADPX(600,4)
        INTEGER CONTOR(15),INTVL(15),UPLIM(15),LOWLIM(15),CHREP(13,4),
        DATA ((CHREP(I,J),J=1,4),I=1,13)/' ',' ',' ',' ',' ',' ',' ',
        1 [illegible]'O',' ',' ',' ','O','-',' ',' 
        2 ' ','X',' ','-',' ',' ','X','=',' ',' ',' ','O','X','-',' ','O','X','=
        3 ' ','M','E','W',' ','O','X','A','V','O','X','I','H'/
        DATA IR,IW/24,23/
        OPEN(UNIT=07,DEVICE='DSK',FILE='HRDCP1')
        OPEN(UNIT=08,DEVICE='DSK',FILE='HRDCP2')
*       OPEN(UNIT=09,DEVICE='DSK',FILE='HRDCP3')
*       OPEN(UNIT=10,DEVICE='DSK',FILE='HRDCP4')
*       OPEN(UNIT=11,DEVICE='DSK',FILE='HRDCP5')
*       OPEN(UNIT=IR,DEVICE='DSK',FILE='INPUT')
*       ITTERT=ITTERT+1
*       TYPE 200,ITTERT
        TYPE 201
        ACCEPT *,NCLASS
        TYPE 202
        ACCEPT *, (GRAY(I),I=1,NCLASS)
        TYPE 203
        ACCEPT 211, DECIND
        IF(DECIND.EQ.'HRD') GOTO 113
        DO 107 I=1,NCLASS
        TYPE 204,I
        ACCEPT *, LOWLIM(I),UPLIM(I)
107     CONTINUE
113     CONTINUE
        TYPE 205
        ACCEPT *, NPIX,NLINE
        TYPE 206
        ACCEPT *,NBR,NBC
        ISTPXL=NBC
        DO  104 I=1,NPIX
        HEADPX(I,1)=NBC/1000
        HEADPX(I,2)=(NBC-HEADPX(I,1)*1000)/100
        HEADPX(I,3)=(NBC-HEADPX(I,1)*1000-HEADPX(I,2)*100)/10
        HEADPX(I,4)=NBC-HEADPX(I,1)*1000-HEADPX(I,2)*100-HEADPX(I,3)*1
        NBC=NBC+1
104     CONTINUE
        IFINL=0 ; IW1=07
105     CONTINUE
        INITL=IFINL+1 ; IFINL=INITL+119
```

```
          IF(IFINL > NPIX) IFINL=NPIX
          WRITE(IW1,207) ((HEADPX(I,J),I=INITL,IFINL),J=1,4)
          WRITE(IW1,208)
          IW1=IW1+1
          IF(IFINL < NPIX) GOTO 105
          DO 101 IL=1,NLINE
          TYPE *,IL
*         IBR=NBR+(IL-1)
*         READ(IR,*) (IPIX(I),I=1,NPIX)
          CALL PIXEL(IPIX,NPIX,ISTPXL,IBR)
          DO 100 I=1,NPIX
          DO 100 J=1,4
 100      INTMAP(I,J)=' '
          DO 111 I=1,NPIX
          IF(IPIX(I) < 0) IPIX(I)=IPIX(I)+256
          IF(DECIND.EQ.'HRD')  GOTO 114
          DO 102 J=1,NCLASS
          IF((IPIX(I).LE.UPLIM(J)).AND.(IPIX(I).GE.LOWLIM(J))) GOTO 108
          GOTO 102
 108      CONTINUE
          DO 110 I1=1,4
          INTMAP(I,I1)=CHREP(GRAY(J),I1)
 110      CONTINUE
*         GOTO 102
 102      CONTINUE
 114      CONTINUE
          IF(DECIND.EQ.'DEN') GOTO 111
          IND=(IPIX(I)/13)+1
*         TYPE *,IND,IPIX(I)
          DO 112 I1=1,4
          INTMAP(I,I1)=CHREP(GRAY(IND),I1)
 112      CONTINUE
 111      CONTINUE
          IFINL=0 ; IW1=07
 103      CONTINUE
          INITL=IFINL+1 ; IFINL=INITL+119
*         TYPE *, INITL,IFINL,NPIX
          IF(IFINL > NPIX) IFINL=NPIX
          WRITE(IW1,209) IBR,IBR
          WRITE(IW1,210) ((INTMAP(I,J),I=INITL,IFINL),J=1,4)
          IW1=IW1+1
          IF(IFINL < NPIX) GOTO 103
 101      CONTINUE
          IFINL=0 ; IW1=07
 106      CONTINUE
          INITL=IFINL+1 ; IFINL=INITL+119
          IF(IFINL > NPIX) IFINL=NPIX
          WRITE(IW1,208)
          WRITE(IW1,207) ((HEADPX(I,J),I=INITL,IFINL),J=1,4)
          IW1=IW1+1
```

A P P E N D I X


```
      IF(IFINL < NPIX) GOTO 106
200   FORMAT('   LINE NUMBER OF LINE WHICH HAS BEEN MAPPED ',I4)
201   FORMAT('   TYPE IN NUMBER OF CLASSES FOR SLICILNG')
202   FORMAT('   TYPE IN INDICATORS FOR REPRESENTATION OF CLASSES')
203   FORMAT('   TYPE THE INDICATOR AS :''HRD'' OR ''DEN''')
204   FORMAT('   TYPE IN LOWER AND UPPER LEVELS',I5)
205   FORMAT('   TYPE IN TOTAL NUMBER OF PIXELS AND LINES')
206   FORMAT('   TYPE IN THE FIRST LINE No AND PIXEL No')
207   FORMAT(6X,120I1)
208   FORMAT(' ')
209   FORMAT(I5,121X,I5)
210   FORMAT('+',5X,120A1)
211   FORMAT(A3)
      STOP
      END
*************************************************************************
*     Subroutine PIXEL(ABC,ILENTH,IPIX,LINE)
*     This program is to read a record of the CCT to get the
*     gray level of certain pixel whis has to be fed into
*     program while under execution.
*     This program read a part of the record starting from NPIX to
*     NPIX + ILENTH
*************************************************************************

      SUBROUTINE PIXEL(ABC,ILENTH,IPIX,LINE)
      INTEGER OCT(1124),BT1,BT2,BT3,BT4,BYTE(4500)
      INTEGER RECORD,BAND,ABC(600)
      DATA IW/5/
*     OPEN(UNIT=50,DEVICE='DSKC',FILE='INP')
      OPEN(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1124,
     1DENSITY='1600')
      READ(20)OCT
      J=1
      DO 101 I=1,1124
      BT1=OCT(I)/2^28
      BYTE(J)=BT1 ; J=J+1
      BT2=(OCT(I)-BT1*2^28)/2^20
      BYTE(J)=BT2; J=J+1
      BT3=(OCT(I)-BT1*2^28-BT2*2^20)/2^12
      BYTE(J)=BT3; J=J+1
      BT4=(OCT(I)-BT1*2^28-BT2*2^20-BT3*2^12)/2^4
      BYTE(J)=BT4; J=J+1
101   CONTINUE
      RECORD=BYTE(3)+BYTE(4)*256
      LINE=BYTE(7)+BYTE(8)*256
      BAND=7-(LINE*4-RECORD)
      WRITE(IW,200) LINE,IPIX
200   FORMAT(15X,'LINE NUBER= ',I4,'  PIXEL NUMBER =',I5)
      WRITE(IW,201)BAND,RECORD
```

A P P E N D I X


```
201     FORMAT(/,15X,'BAND  =',I4,'    RECORD NUMBER = ',I5)
        IZERO=1
        DO 104 I=9,400
104     IF (BYTE(I).EQ.0) IZERO=IZERO+1
        IPIXEL=IPIX+IZERO+8
        IPIXU=IPIXEL +(ILENTH-1)
        IPIXL=IPIXEL
        J=1
        DO 102 I=IPIXL,IPIXU
        ABC(J)=BYTE(I)
        J=J+1
102     CONTINUE
        DO 100 I=1,3
        READ(20) OCT
100     CONTINUE
        CLOSE(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1124,
        1DENSITY='1600')
*       WRITE(50,114) (BYTE(I),I=IPIXL,IPIXU)
*       WRITE(IW,114)ABC
114     FORMAT (//(4X,30I4))
        RETURN
        END
```

```
*******************************************************************************
*           This program TAPEMR FOR reads whole record of the CCT
*       at a stretch .It also mensions the current record number , sca
*       n line number and the band sequence number to which the partic
*       ular record belongs . It tabulates the reflectance values of
*       the record giving the the number of zeros encountered .
*******************************************************************************
        INTEGER REFVEL(1124),BYTE1,BYTE2,BYTE3,BYTE4,FORREF(32),ITAB(3
        INTEGER SCNLIN
        DATA II,ITAB/1,30*0/
*       OPEN(UNIT=53,DEVICE='DSK')
*       OPEN(UNIT=45,DEVICE='DSKC',FILE='WELDAT',ACCESS='APPEND')
        OPEN(UNIT=45,DEVICE='DSKC',FILE='REF')
        OPEN(UNIT=20,DEVICE='MTA0',MODE='DUMP',RECORD SIZE=1124,DENSIT
        1='1600')
        DO 102 I=1,30
102     ITAB(I)=0
        READ(20)REFVEL
        IZERO=0
        DO 100 I=1,1124
        BYTE1=REFVEL(I)/2**28
        FORREF(II)=BYTE1
        BYTE2=(REFVEL(I)-BYTE1*2**28)/2**20
        FORREF(II+1)=BYTE2
        BYTE3=(REFVEL(I)-BYTE1*2**28-BYTE2*2**20)/2**12
        FORREF(II+2)=BYTE3
        BYTE4=(REFVEL(I)-BYTE1*2**28-BYTE2*2**20-BYTE3*2**12)/2**4
        FORREF(II+3)=BYTE4
*       WRITE(53,105)BYTE1,BYTE2,BYTE3,BYTE4
*       TYPE *, REFVEL(I),BYTE1,BYTE2,BYTE3,BYTE4
*105    FORMAT(4I5)
        II=II+4
*       TYPE *,I
        IF(II<=32) GOTO 100
        IF(I <= 8) GOTO 104
        DO 103 J=1,32
        IF(FORREF(J).EQ.0) IZERO=IZERO+1
        IF(FORREF(J) < 0) FORREF(J)=FORREF(J)+256
        IND=(FORREF(J)/10)+1
*       TYPE *,IND,FORREF(J),I
        ITAB(IND)=ITAB(IND)+1
103     CONTINUE
104     CONTINUE
        IF(I.NE.8) GOTO 101
*       TYPE *,FORREF(3),FORREF(4),FORREF(7),FORREF(8)
        SCNLIN=FORREF(7)+(FORREF(8)*256)
        IBND=FORREF(3)+(FORREF(4)*256)
        IBAND=7-(SCNLIN*4-IBND)
101     CONTINUE
        WRITE(45,106) FORREF
```

```
106     FORMAT(2X,32I4)
        IT=1
100     CONTINUE
        ITAB(1)=ITAB(1)-IZERO
        CLOSE(UNIT=20,DEVICE='MTA0',MODE='DUMP',RECORD SIZE=1124,DENSI
       1SITY='1600')
        WRITE(45,110) SCNLIN,IBAND
        WRITE(45,107) ITAB , IZERO
107     FORMAT(/////6(45X,5I7/),60X,I8)
        TYPE 108,SCNLIN,IBAND
108     FORMAT(4X,'SCAN LINE NUMBER 'I6,'      BAND ',I4)
110     FORMAT(////46X,'SCAN LINE NUMBER 'I6'      BAND',I4)
        TYPE 109, ITAB,IZERO
109     FORMAT(6(4X,5I7,/),15X,I10)
        STOP
        END
```

A P P E N D I X


```
**********************************************************************
*       THIS PROGRAM CONVERTS THE LATITUDES AND LONGITUDES OF A GIVEN
*       POINT ON THE EARTH'S SURFACE TO ITS LINE NUMBER AND PIXEL
*       NUMBER ON THE IMAGERY AFTER CONVERSION TO CONICAL ORTHOMORPHIC
*       CO-ORDINATES. THE CONSTANTS IN THIS PROGRAM ARE VALID ONLY FOR
*       THE VARANASI-GHAZIPUR-JAUNPUR AREA.
**********************************************************************

        IMPLICIT DOUBLE PRECISION(A-H,K-Z)
        DIMENSION LAT(150),LONG(150),LATRAD(150)
        DATA IR,IW/22,23/
        IND007=1
        LONG0=81.0
        LAT0=24.5*3.1415921/180.0
        A=6377277.6
        ELLIP=1.0/300.8
        ELLIP=ELLIP*ELLIP
        SIN=DSIN(LAT0)
        SINSQ=SIN*SIN
        DENOM=1.0-ELLIP*SINSQ
        NO=A/DSQRT(DENOM)
        R0=NO*((1.0-ELLIP)/DENOM)
        P=NO*(DCOS(LAT0)/DSIN(LAT0))
        RM=DSQRT(R0*NO)
*       PRINT1
        READ(IR,*)II
        WRITE(IW,203)
        DO 100 I=1,II
*       READ(IR,*)LAT(I),LONG(I)
        READ(IR,*)IDEG1,IMIN1,SEC1,IDEG2,IMIN2,SEC2
        LONG(I)=IDEG2+IMIN2/60.0+SEC2/3600.0
        LAT(I)=IDEG1+IMIN1/60.0+SEC1/3600.0
        LATRAD(I)=LAT(I)*3.1415926/180.0
        LONGDF=LONG(I)-LONG0
        GAMMA=LONGDF*SIN
        GAMMA=GAMMA*3.1415926/180.0
        M=RM*(LATRAD(I)-LAT0)
        M1=M**3/(6.0*R0*NO)
        TAN=DSIN(LAT0)/DCOS(LAT0)
        M2=M1*(M*TAN/(4.0*NO))
        M11=M+M1+M2
        X=(P-M11)*DSIN(GAMMA)
        GAMMA=GAMMA/2.0
        Y=M11+X*(DSIN(GAMMA)/DCOS(GAMMA))
        B1=66.44746
        B2=-9.796144
        A1=-11.22251
        A2=-74.31621
        C1=X-71452.41
        C2=Y-271935.3
```

```
        X1=(B2*C1-B1*C2)/(A1*B2-A2*B1)
        ILIN=X1+0.5
*       TYPE*,ILIN
        ILIN1=ILIN*4
        Y2=(A2*C1-A1*C2)/(A2*B1-A1*B2)
        IPIX=Y2+0.5
        IF(IND007.NE.6) GOTO 101
        IND007=1
        WRITE(IW,202)
101     CONTINUE
        WRITE(IW,201) IDEG1,IMIN1,SEC1,IDEG2,IMIN2,SEC2,ILIN,IPIX
        IND007=IND007+1
        1XEL'/6X,54('-'))
100     CONTINUE
201     FORMAT(6X,2(2I4,F7.2,5X),I4,5X,I4)
202     FORMAT(' ')
203     FORMAT(6X,54('-')/9X,'LATITUDE',13X,'LONGITUDE',7X,'LINE',4X,'
        STOP
        END
```